ILIR '00:
SSC San Diego
In-House Laboratory
Independent Research
2000 Annual Report

SSC San Diego
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ADMINISTRATIVE INFORMATION

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INTRODUCTION

INTRODUCTION

This document is the report for the fiscal year (FY) 00 Navy In-House Laboratory Independent Research (ILIR) program at the Space and Naval Warfare Systems Center, San Diego (SSC San Diego). ILIR enables SSC San Diego to perform innovative, promising research consistent with its mission and with the policies of the Chief of Naval Research and the Department of the Navy. The ILIR program is implemented at SSC San Diego under the authority of the Deputy Executive Director for Science, Technology and Engineering and is managed by the Science and Technology Office. Total funds of $2,406,481 were provided in FY 00. In addition, $300,000 was carried over from the FY 99 program and used to begin restructuring aimed at increasing program impact.

The ILIR program at SSC San Diego is being restructured to increase the impact of limited ILIR resources. This reorganization will increase the size of selected projects to focus on areas identified by our corporate technical vision as most critical to the SSC San Diego mission. When fully implemented, there will be three to six large team projects in progress each year. The team projects will be funded at approximately $300K per year and will generally last for 2 to 3 years. The rest of the program will comprise smaller projects, each funded at $100K to $150K per year, up from previous averages of approximately $80K each. The intent is to fund the most mission-critical projects at high levels to enable exceptional impacts, and to fund all projects at adequate levels to generate useful results. Consequently, a smaller number of projects overall will be funded in FY 01 than were funded in previous years. In FY 99, there were 29 projects with an average funding of $77K; in FY 00, there were 28 projects with average funding of $97K; and in FY 01, there are 17 projects with an average funding of $151K.

Two large team projects were initiated in FY 00: *Knowledge Mining for Command* and *Control Systems* and *Robust Waveform Design for Tactical Communication Channels*. For FY 00, these projects were funded at $295K and $385K respectively. These projects are expected to continue for 2 to 3 years, and additional team projects will be selected in FY 01 and subsequent years.

In terms of productivity statistics, the FY 00 ILIR program was very successful, with a total of 89 papers/proceedings/books/dissertations published or submitted and 62 presentations made by SSC San Diego ILIR investigators. There were also 7 ILIR-related patents, 15 patent applications, and 18 patent disclosures produced during FY 00.

Because the ILIR program comprises basic research, the impact on the Fleet occurs over a period of years or decades, with many impacts being an indirect and cumulative result of contributions to scientific knowledge. While most of the ILIR work leads to incremental improvements in existing components and subsystems, some projects may lead to significant new systems. Examples of potential impacts are contained in the report.

Oversight responsibility for the ILIR program was moved to the Office of Naval Research (ONR) Chief Scientist's Office in October 1999. This move resulted in a complete revision of program guidelines. The new guidelines stress increased collaboration and participation of new scientists and strongly encourage teams of investigators to work on projects of sufficient scope and risk to have a potentially significant impact on Department of the Navy (DoN) priorities. The initiatives implemented by SSC San Diego in FY 00 and FY 01 programs are responsive to the new guidance from ONR.

The following table summarizes recent metrics for the SSC San Diego ILIR program.

Fiscal Year	FY 95	FY 96	FY 97	FY 98	FY 99	FY 00	FY 01
Funding ($K)	2,463	2,763	2,521	2,300	2,240	2,706	2,575
Number of projects	29	31	29	25	29	28	17
Refereed papers (published or accepted)	26	19	19	15	22	18	
Refereed papers (submitted)	9	9	10	5	10	17	
Books/chapters	—	—	—	3	9	1	
In-house publications	3	4	2	2	—	3	
Proceedings (counted in presentations before '98)	—	—	—	30	26	50	
Presentations to professional meetings	60	38	50	42	52	62	
Patents issued	5	6	7	5	11	6	
Claims allowed, pending issue	2	—	2	4	5	1	
Patent applications filed	6	11	12	11	7	11	
Invention disclosures authorized	5	6	4	3	3	4	
Invention disclosures submitted	7	7	10	13	17	18	

PROJECT SUMMARIES

Command and Control

Change Blindness: Understanding Our Visual Representation of Objects and Scenes

Dr. Joseph DiVita,
D44209, (619) 553–6461

"Change blindness" refers to the phenomenon that humans are often unable to detect major changes in objects from one scene to the next. Future naval information and control workstations will provide large, physically dispersed, screen areas that will require operators to shift their attention from one display to another—a departure from current "single task/single display" command and control consoles. This diversion of attention creates an opportunity for changes to be made to unattended screens and can result in potentially disastrous consequences. Our research presents data on the occurrence of change blindness in a tactical scenario. On a sparse tactical display comprised of only eight contacts of interest, observers demonstrated a considerable degree of change blindness. These changes were task-relevant and critical to the operator's situational awareness and task of monitoring the air space. For 28.5% of the critical changes tested, the observers were unsure as to what contact had actually changed on the display. On 17.4% of the trials, observers grossly guessed at what change took place. Thus, change blindness occurs in the Combat Information Center (CIC) environment.

INTRODUCTION

With clarity of vision, we apprehend a world filled with numerous objects and surfaces—a world rich with detail—or do we? Perhaps no other visual phenomenon challenges our naïve visual impression of the world than "change blindness." Change blindness refers to the striking phenomenon that humans are often unable to detect major changes in objects from one scene to the next. (See [1] for a review.) Change blindness has been demonstrated using several different research paradigms. These paradigms include (1) changes made during a blank interval between two scene presentations; (2) changes made while the observer blinked or made a saccade while viewing a scene; (3) changes made when a set of dot patterns (a "mud splash") was simultaneously superimposed onto the scene; (4) changes made to an actor during a "cut" in a motion-picture scene; and (5) changes made during a "real-world occlusion event." In all these cases, striking changes in objects were not perceived from one view to the next.

The inability of observers to detect changes under a variety of conditions has lead investigators to conclude that the information encoded at any one moment in the visual scene is very selective. The argument for this conclusion is as follows. To detect a change, the observer must engage in a comparison process between the two images—the current, or new scene, must be compared to the prior, or old scene. Our inability to detect these changes implies that very little information concerning the original scene has been encoded into working visual memory—hence, the inefficiency of the comparison process.

A second conclusion drawn from the change blindness phenomenon is that attention is specifically required to perceive change. The observer must attend to an object at time 1 in order to detect a change to the object at time 2. The implication of this conclusion is far-reaching since the deployment of

attention is generally believed to be a serial process; that is, attention can only be focused on one object at a time. If the deployment of attention is serial and if attention is required to perceive change, then we must conclude, as several investigators have, that the detection of change is a relatively slow, serial process.

The change blindness phenomenon is potentially relevant to many work-related and applied settings. The purpose of the current study was to test if the naval Combat Information Center (CIC) console operator experienced change blindness. CIC operators monitor military information and control workstations. Examples of civilian information and control systems are found in the nuclear power industry, air traffic management, law enforcement, surveillance, and medical operating and emergency rooms. Operators of these systems are heavily loaded with visual-search, situation-assessment, voice-communications, and control-display-manipulation tasks. These tasks must often be performed concurrently. To perform multiple tasks, the interface design typically provides large, physically dispersed, screen areas that require operators to shift their attention from one display to another as they shift their attention from one task to another. This diversion of attention creates an opportunity for changes to occur on unattended screens. The result is that change blindness can occur with potentially negative consequences.

PROCEDURE

One task of a CIC console operator is to monitor the air traffic as depicted on a tactical display. As aircraft fly into and leave the monitored airspace, the information on tactical displays associated with these aircraft changes: (1) new aircraft can enter the airspace appearing on the display for the first time or (2) attributes of existing contacts can change. For example, aircraft can change their course, range, bearing, speed, and altitude. Attributes of aircraft often change. In fact, attributes such as range and bearing are constantly changing; however, the vast majority of these changes are not tactically significant, and it would not be surprising if an operator was not aware of them. In our experiment, 16 tactically significant attribute changes that are depicted directly on the tactical map were first identified. These changes are critical because (1) they may lead the operator to question the amity classification of the contact or (2) the contact has entered into a relationship with ownship or another aircraft that is tactically significant to the operator's situational awareness. In addition to attribute changes to existing contacts, new contacts may appear on the map for the first time. Six different ways that contacts may enter the airspace were identified and tested.

Two tactical scenarios each composed of eight air contacts and eight non-air contacts were generated that incorporated the 21 critical changes. Eight non-air contacts were added to lend realism to the scenarios (e.g., airplanes land and take off from airports, so airports were depicted). All actions of contacts in the scenario were realistic. The basic idea of the experiment was as follows: The operator was given the task to monitor the air space and report significant changes to aircraft actions. Operators could "click on" the contacts and obtain information (course, speed, range, bearing) just as in an actual tactical display. In addition to monitoring the airspace, the operator had to respond to alerts and notifications that appeared on a separate monitor. The alerts and notifications were relevant to the information depicted on the tactical display and sometimes called for the operator to access information on the tactical display by correctly answering a question. The alerts and notifications were designed to lend realism to the operator's task.

On critical trials, the tactical display was blanked and the operator was informed, on the alert display, that a significant change had taken place on the tactical display. The nature of the change was specified for each of the critical questions. Operators were instructed to report the change by clicking on the appropriate contact. For example, "An aircraft has significantly changed its course. Please hook this aircraft and report its new course." After acknowledging this "alert," the tactical display reappeared, and the operator "clicked on" contacts until the correct contact was identified. The operator was given immediate feedback as to the correctness of each of their selections.

During the scenario, the number of contacts of interest (the air contacts) remained constant when testing for perceived change. The scenario started with seven contacts of interest. The first test for change blindness entailed adding a new contact. The scenario then proceeded, but before another new contact was added to the display, one of the contacts flew out of the airspace, and thus off the display. In this manner, set size was held at a constant eight contacts when the operator was asked to detect a change.

Data were collected on the number of clicks it took the operator to correctly identify the contact. In this experiment, the number of clicks was indicative of the operator's ability to detect that change. For example, if there are *n* aircraft on the display and the operator has no idea which contact changed, then the operator is essentially engaged in a random search. It will take *n/2* clicks on average to hook the correct aircraft. In contrast, if the operator easily detects the change, then only one click would be required to correctly identify the contact.

A second issue that was tested was whether context was important to detect change. To test this, each scenario could be run with or without tactical graphics that included a weapons range capability and commercial air corridors. Eight conditions were identified as dependent contextually on the tactical graphics. Twenty-eight SSC San Diego and Pacific Science and Engineering employees familiar with tactical displays and the task of monitoring the airspace were tested on each of the scenarios: one scenario with the tactical graphics present and one without. Across subjects, the order of presentation of the scenarios and the order of presentation of displays with or without the tactical graphics was counterbalanced.

RESULTS

For 28.5% of the critical changes tested, the observers were unsure as to what contact had actually changed on the display since it took them two or more mouse clicks to correctly identify the contact. On 17.4% of the trials, observers grossly guessed at what change took place (three or more clicks). In addition, when no background graphics were present, there was significantly more guessing on the eight conditions identified as semantically sensitive to the background tactical graphics as a reference.

Two control conditions were also tested. In the first control condition, to demonstrate that the changes made to the display are easily detected if the operator's attention is not diverted, two observers were asked to detect changes while viewing the display. Under these conditions, one image follows the other, and the change is perceived as motion or abrupt onset (if a new contact appears). The detection of change under these conditions was quite easy since the detection is based on perceiving local transients and is synonymous to motion detection. In the second control condition, context was completely eliminated, and the same changes were tested using a "flicker paradigm." Five observers

first saw a tactical picture, followed by a blank screen, followed by a change to the tactical picture, and were asked to detect the change by clicking on the changed contact. Results for this experiment were similar to the main experiment in that subjects exhibited uncertainty on approximately 25% of the trials.

CONCLUSIONS

Change blindness occurs in the CIC environment, and the implication is that tactical situations entailing greater numbers of contacts of interest can expect the effect to be even more severe.

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Distributed Quality Collaboration

John Drummond
D4123, (619) 553–4131

This work characterized a method for providing timeliness quality to the distributed collaboration environment. The approach was to investigate how a specific system can mitigate resource-utilization timeliness requirements within end-to-end quality of service environments. This investigation took an in-depth look at various systems, at the kernel and middleware levels, located within the SSC San Diego Quorum project testbed. Detailed timeliness analysis focused on the elements of bandwidth levels, levels of reliability, jitter, and controlled variable latency levels. Specific command and control data (typical of normal operating environments) were calculated for input into the testbed control systems. The system-timing data were measured, recorded, and carefully assessed based on correctly perceived situations. This timeliness is an important principle in the coherence of data within a given flow. This flow, in turn, has a direct bearing on the consistency of a given situation perception. Resource management within a distributed environment is a critical element for maintaining a timely flow of cognitive data and, therefore, highly relevant to Department of the Navy (DoN) distributed command and control systems.

BACKGROUND

The military distributed command and control environment is a demanding framework that requires transformation as rapidly as the pace with which our contemporary technology advances [1]. The requirements of command and control systems are extremely unstable and changeable due to tactical surprises, changes in goals and missions, etc. Currently, an ever-increasing level of distributed programs requires conventional end-to-end service guarantees [2]. Next-generation distributed real-time applications, such as teleconferencing, avionics mission computing, and process control, require end systems that can provide statistical and deterministic quality of service (QoS) guarantees for latency, bandwidth, and reliability. Programs that require consistent situation perception for collaborative planning and decision-making fit into this taxonomy. These guarantees include elements of bandwidth level requirements, selectable levels of reliability, adjustable jitter, and controlled variable latency levels. The timeliness of a given data flow and the end-to-end service provisions previously mentioned are based on the resource management of the systems along this flow path.

Current work in this area is focused on implementation of the end-to-end timeliness service. However, the timely resource management of this service is the paramount issue [3]. Technology currently exists for QoS at a reasonable resource cost. However, there is a highly variable costing structure, and the bulk of the overhead is in managing QoS, not in just making it available.

Other current work focuses on managing the path itself [4]. We need a Path Information Base to provide information on available paths and to put the information on a separate server rather than add it to the list of things that routers do (they are already busy). This will allow for the organization of a hierarchical pathway structure, but we still need timely management of resource utilization at the individual system level to complete the end-to-end cycle.

INTRODUCTION

This work characterized a method for providing a timeliness quality to the distributed command and control environment. Timeliness is an important principle in the coherence of data within a given flow. This flow, in turn, has a direct bearing on the consistency of a given situation perception. Resource management within a given system residing on a distributed command and control environment is a critical element of maintaining a timely flow of cognitive data. Yet, this critical element has been given minimal attention during the development of command and control systems. Therefore, the focus of this project was to investigate the development and maturation of potential timeliness proof algorithms that could be applied to distributed command and control environments.

APPROACH

The approach to this work was based on the presumption that systems within a distributed end-to-end command and control path must support resource management within a specific timeliness parameter to achieve proper situation assessment. Without this support, the possibility exists for a given situation to be perceived through late or out-of-order input data. This false situation assessment could then lead to pursuit of a flawed or faulty decision.

Our characterization work investigated how a specific system can mitigate resource-utilization, timeliness-requirement difficulties within end-to-end QoS environments. We took an in-depth look at various systems at the kernel and middleware levels by using the local SSC San Diego Quorum project testbed. The detailed timeliness analysis focused on the elements of bandwidth levels, levels of reliability, jitter, and controlled variable latency levels. Specific command and control data (typical of normal operating environments) were input into the testbed control systems, whereby the system timing data were measured, recorded, and carefully assessed based on correctly perceived situations. The possible use of lightweight inference was also examined. The development of system models could be used based on this inference technique.

RESULTS

Partial results of the first-year effort of this multi-year project include an initial analysis on the Naval Surface Warfare Center's HiperD system, which consists of an Aegis simulator testbed with embedded command and control elements. We developed a critical load and a timeliness-characteristics requirements list with granularity to the millisecond level based on the input received from team-member NSWC HiperD experiments. These critical characteristics included (1) track-processing capacity, categorized high-interest tracks; (2) background-type tracks; (3) the track-delivery aging timing range, both for high-interest and background tracks; (4) detection times for group member failures; (5) single-computer failure detection timing; (6) individual process recovery times dependent on the process context information availability and interdependencies; (7) 10 groupings of processes lost recovery times—(these times were all for no-context data, minimum-context data, and ample-context data); and (8) the latencies between communicating applications (based on a 128-byte message). We also proceeded with the initial stages of model development for distributed command and control environment elements.

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Adaptive Intelligent Agents in Informative Environments

Brenda J. Powers
D4123, (619) 553–4808

Command and control (C2) application environments are dynamic and non-deterministic. Thus, there are unique challenges involved in incorporating intelligent-agent technology within them. Decision-makers are required to assess and solve a variety of problems as quickly as possible, at times without adequate resources. This research sought to prove that the incorporation of agent technology into C2 application environments offers great benefit through human–computer collaboration to assist decision-makers in carrying out mission-related activities. The research effort investigated the types of tasks best suited for agents used in C2 application environments, explored the challenges involved in using agent technology within C2 application environments, and studied some of the on-going research being undertaken in the area of intelligent-agent technology. Accomplishments include the establishment of working relationships with some of the most knowledgeable people involved in the research of agent technology, and the completion of a paper entitled "Adaptive Intelligent Agents in Informative Environments: Human–Computer Collaboration in Command and Control Application Environments."

The need for automating methods of accomplishing military command and control (C2) activities is of utmost importance in today's military mission planning and execution operations. In combat, effective C2, as well as success in battle, requires commanders to develop associations and thought patterns. During a contingency, military commanders and their staffs are required to make timely and effective decisions under pressure. Decision-makers often spend too much time manipulating information systems to filter data into meaningful information. They also spend too much time performing simple tasks in order to assess the situation to prepare and execute plans. Currently, most military C2 activities performed by decision-makers are accomplished via paper and voice circuits. Toward this end, technology, based on intelligent agents acting autonomously to perform user-specified tasks, offers the potential to automate and speed up many of these time-critical activities. This research focused on human–computer collaboration within the context of a specific C2 application domain example.

This research required an understanding of the issues involved in C2 operations so that correct assumptions could be made on how to apply agent technology. The C2 application environment of air defense was also studied to determine if some specific task agents could be assigned to assist decision-makers in littoral air defense. It was found that, in this type of mission, the geographical constraints of the battle space, and the evaluation of the enemy and assessment of its capabilities, must be considered. It was concluded that agents with expert knowledge of the specifics of the topology of this region could take the initiative, generate potential plans for attack/defense, and present the plans to human decision-makers for acceptance or rejection [1]. Some additional tasks identified that agents could best perform in a littoral air-defense environment included assisting decision-makers in maintaining situational awareness, keeping track of both friendly and enemy logistics, monitoring weather conditions, and gathering data on the communication protocols for each asset in the battle space and producing a report [1]. It was concluded that agents need to maintain a

minimal degree of autonomy in order to be of maximum use to decision-makers involved in performing their mission-related C2 activities.

This research effort also required an understanding of cognitive psychology with respect to agents' involvement in human–computer collaboration. For example, consider the fact that, in the heat of a contingency, decision-makers are already under an incredible amount of stress, and it has been proven that declarative memory power is reduced. Today, a decision-maker must commit to memory a knowledge of enemy capabilities; this involves the analysis of all the ships, aircraft, and submarines that could be encountered. Clearly, this is not a trivial task. Therefore, it was concluded that agents with expert knowledge could provide platform-specific guidance when the need arose, thereby reducing chances of error in decision-making.

This research investigated and reported on three research efforts that have developed agent architectures designed to provide agents with the needed attributes to operate in dynamic environments [1]. In conjunction with this, examples of how the agents, based on these architectures, were used in systems to support human–computer collaboration were also studied. The research efforts investigated were the Sensible Agent program at the Laboratory for Intelligent Processes and Systems at the University of Texas at Austin; the Integrated Marine Multi-Agent Command and Control System (IMMACCS) developed by the Collaborative Agent Design (CAD) Research Center at Cal Poly San Luis Obispo; and the Soar project developed at the University of Southern California (USC), Intelligent Systems Division (ISI).

Finally, it was determined that future research is required to establish the degree to which agents should remain autonomous when acting in the capacity of planning and decision aids for military decision-makers. Additional research is also needed to prove that the tasks identified by this research are, in fact, the types of tasks that are best suited to agents operating in C2 application environments.

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Integration of Complex Information

Douglas S. Lange
D44207, (619) 553–36534

This research seeks to define a mechanism to allow complex nonspecified information to be integrated and utilized. The method being explored uses open hypermedia architectures and lightweight inference to manage and use information. Successes to date have included (1) the definition of a hypermedia framework that can be used for intelligence analysis and plan description and tracking, (2) identification of two inference strategies to be explored, and (3) the successful transition of the hypermedia framework to a development project. The emphasis for the final year of this effort will be on implementing and evaluating the inference strategies and demonstrating the ability to infer some information from the hypermedia framework.

SUMMARY

Command and control involves three fundamental processes that fit together in a tight cycle. Situation analysis provides the context on which to act. Decisions are made based on the analysis results. These decisions constitute planned movements, engagement orders, and many other possible actions. Decisions must be communicated to those who are to carry out the actions. The results of these actions are observed and folded into a new situation analysis.

As command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems have evolved, system integration has been the general theme. Stand-alone systems, each with its own database, were first interfaced to allow some transfer of data. Data management schemes were implemented to provide some consistency among databases and operational units. System federation gradually allowed multiple applications to run on users' workstations, preventing the need for specialized hardware and support software for large numbers of individual systems. The current state of system integration not only allows multiple applications to share hardware, operating system, and network platforms, but also utilizes a layered service architecture to eliminate redundancy of some capabilities.

The evolution of system integration has broadened the stovepipes that were so narrow in previous system generations. The resulting view is of a few very broad systems made up of many small applications, any of which may be accessible through the workstation in front of the user. Some applications work on common data managed through centralized services. However, many categories of data still form separate stovepipes since they are maintained in separate data servers due to their differing technical natures and programmatic backgrounds. It is left to mental effort by the users to associate the tactical situation shown in one application with the results of a logistical query conducted through another.

INFORMATION COMPLEXITY

The focus on systems integration ignores the true goal in decision support. It is the information that is of ultimate value to the decision-makers. Integrating the information is the next step. However, military information is not a simple matter of collecting and crunching sales and inventory figures

from various branch offices as found in data warehousing applications. The domain of the military environment is complex. The variety of concepts, events, and situations that can be described subjectively or measured and reported objectively is probably limitless. No ontological study can *a priori* determine all of the possible data types needed to describe the military environment. Therefore, information integration is not going to be completely accomplished through bringing all data into a relational or object database.

A PATTERN OF ANALYSIS

In researching the requirements for an intelligence support system for the Defense Intelligence Agency (DIA), a pattern of analysis was uncovered that was common to a pattern used in some other domains. The primary feature of this pattern is that analysts create associations among existing data. Analysts rarely create data, but search, filter, and review all available information. As they do, they form networks of related information

Current practice involves DIA intelligence analysts spending a portion of their time building up a private model of their area of expertise. The remainder of their time is spent responding to queries from DIA's various customers. The responses typically take the form of linear essays. Analysts also periodically produce background reports on particular matters of interest. These, too, take a strictly linear, book-like form even when delivered over a computer network.

The results of the current approach included the following problems:

- The products were static or updated on a paper publishing timeframe.
- Customers with local information were unable to share with others.
- Only a particular question was answered, even if it was not the correct question.
- Analyst turnover caused a large loss of knowledge.

As a result of these insights, work was initiated to find a way of recording the knowledge being built by the intelligence analyst and communicating this knowledge to intelligence consumers. The goal was to move away from the linear essay and its strict segregation of reader and writer roles to a more collaborative method of communications that would allow for continuous update of the knowledge jointly held between the intelligence agency and its customers.

RECORDING DECISIONS

Decisions also take the form of associations among data or information elements. A classic example may be the order for a surface combatant to engage a hostile aircraft. The decision-maker did not create the aircraft or the positional and attribute data held on that aircraft. Likewise, the surface com-batant's information was not generated by the decision-maker. The value added by the decision-maker is that an engagement relationship (perhaps with other amplifying information) should exist between the two.

As the data on the two combatants change, the association must be reviewed but is not necessarily invalidated. Likewise, a reversal of the decision changes the relationship among the combatants but does not change any of their individual data. This fundamental distinction between the structural representation of the associations among concepts or real-world objects and the content that describes them is common between the knowledge created by analysts and decision-makers.

USING THE KNOWLEDGE

The intelligence analysis tool built for DIA allows for the storage and retrieval of information from the knowledge base. If this technique is to be used for command and control purposes, the knowledge held in the structure of the hypermedia must be able to be extracted and used. This knowledge can best be described in terms of properties. Some simple properties regarding connectedness and reachability have been defined for the hypermedia. More complex domain-specific properties regarding command and control will be defined using these primitive properties. Inference capabilities will then be added to allow new properties to be inferred and communicated to users.

Two methods of inferring inference are being examined. The first is a general logic-based inference. This will be accomplished by mapping the hypermedia structure to Conceptual Graphs [1]. By accomplishing this, the mathematics behind conceptual graphs will be inherited as will the translation to first-order predicate calculus. The second method of inference will be Lightweight Inference [2]. In lightweight inference, an algebraic language is developed and the well-known mathematics that apply to such languages can be utilized. Less can be inferred using this method, but termination and efficient processing can be guaranteed when such a language can be defined.

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Dynamic Sensor Allocation and Tasking System

John R. McDonnell
D745, (619) 767–6410

The project objective was to research and prototype a Dynamic Sensor Allocation and Tasking (DSAT) system. The purpose of the DSAT system is to support sensor tasking order requests and their near-optimal resolution under time-critical constraints. Currently, resolution of sensor tasking is predominantly an ad hoc endeavor that is resolved based on ownership and availability of assets. The concept of developing and integrating sensor tasking orders into the complex operational environment represents a significant challenge that must be addressed under current concept of operations (CONOPS). This endeavor investigated technologies in distributed computing, software agency, and nondeterministic polynomial (NP)-hard optimization in the context of dynamic sensor tasking. We determined that the DSAT problem can be categorized as a combination of the Generalized Assignment Problem (GAP) and the Multi-Vehicle Routing with Time Windows (MVRTW) problem. A solution approach has been developed and is in the process of being implemented. There are many agent architectures currently available, but none preclude an investigator from undertaking a concerted development effort. An attempt will be made to continue this work under the auspices of the upcoming Decision Support System (DSS) Future Naval Capability (FNC) and/or as a proposed new start under the Office of Naval Research (ONR). Potential transitions include the ongoing Surveillance and Reconnaissance Management Tool (SRMT) and the Real-Time Decision Support (REDS) systems.

SUMMARY

Pre-planned tasking requires the allocation of active and passive sensors for information collection to provide the requisite levels of battlespace awareness and assessment for supporting pre-planned operations (e.g., Bomb Hit Assessment and Battle Damage Assessment). The effectiveness of sensor grids operating in pre-planned mode must be quantified to ensure optimal sensor tasking. Likewise, dynamic sensors provide the commander with the ability to task the sensor grid in real-time to generate battlespace awareness upon demand. This synchronization of resources supports the operational commander's ability to manage battlespace sensor assets to respond to rapidly changing timing, tempo, and priorities of joint operations.

The capability to optimally allocate distributed sensor platforms in light of a mission specific objective is not supported in any integrated tool at this time. Organic sensor assets are controlled currently by Battlegroup Commanders. National and theater assets are controlled by National Command Agencies, thereby introducing an inherent latency to the tactical user. Within the organic sensor spectrum, different command levels make competing requests for a fixed set of sensor assets. These requests are often redundant and must be resolved by the Collection Manager. In the end, the sensor products are generally not readily available to all of the potential customers. Using emerging technologies to address this deficiency in current operational methods would help prevent long-term deficiencies.

With the advent of heterogeneous, distributed computing technologies, such as Java, the benefits derived from using dedicated software processes versus software agents built on a generic agent architecture become a matter of ascertaining whether the potential additional complexity of software agency is warranted for the application. It became apparent that various agent mechanisms currently exist via extensions to the Java Remote Methods Invocation (RMI) package to facilitate many of the functions achieved through dedicated software agency (without incurring the overhead of a multilayer procedure to which many agent-based architectures subscribe).

OBJECTIVE

The project objective was to research and prototype a Dynamic Sensor Allocation and Tasking (DSAT) system. The DSAT system will support sensor tasking order requests and their near-optimal resolution under time-critical constraints. The functionality of the resulting architecture will be to achieve maximal sensor-platform pairings, maintain requestor awareness regarding status, and provide the framework for real-time sensor management and execution monitoring. The near-term objective is to target the organic sensor spectrum with an open, object-based architecture that is readily expandable to both the theater and national levels.

It is envisioned that each tactical user, with proper authority to request sensor tasking/products, will submit his request to the DSAT Object Request Broker (ORB). Software processes will monitor these requests and provide feedback to the users regarding the eventual outcome to their request. Once the collection manager approves a particular sensor tasking order, software agent processes will then be used to task sensor platforms and monitor the resulting sensing tasking order (STO) request. Finally, this information will be provided to execution monitoring tools at the command and field levels.

APPROACH

The overarching goal of the DSAT project is to provide warfighters with an integrated capability for requesting sensor products in the most efficient manner. Using organic in-theater assets, DSAT will allow the warfighter to respond, in real time, to dynamically changing targeting situations. The DSAT prototype represents a unique maturation in applying evolutionary search concepts with case-based reasoning. Objectification of environmental data with management of packaged sensor systems to include product retrieval for real-time decision making will provide unparalleled information availability for decision making. An information management prototype will be integrated with an array of dynamic reasoning tools that will further enhance decision making. Additionally, integrated agent technologies will yield seamless transitions from planning to real-time mission execution and monitoring, while supporting tailored information transfer among planning and operational elements. Thus, the warfighter will realize an increased ability to respond to changing battlefield and operational conditions. An initial undertaking into digitizing the Concept of Operations (CONOPS) and developing an STO in concert with the user community is critical. This integration of the DSAT concept into the operational community represents a nontrivial endeavor. The initial focus will be on organic assets. The philosophy is that as the tactical-level infrastructure is established, with proper system-design foresight, it can then be migrated upward to include interaction with theatre and national assets. In this state-of-the-art concept, real-time replanning and retargeting of in-theater sensors may be achieved.

An object-oriented architecture was developed using Java. A Java-based architecture supports distributed computing functionality including the use of software agents to transfer information from data producers to data consumers in a transparent fashion. The architecture also supports subscription policies for automated information dissemination from the DSAT server. Quality of service can be addressed using processes that are proactive on the user's behalf to automatically keep the client informed of the request status. For example, as users request sensor products, the requests will be automatically transferred to the DSAT ORB. At the ORB, incoming requests will be evaluated for priority and urgency. After the STO is optimized for that snapshot in time, software processes will automatically distribute the STO, along with updates, back to the users so that they can monitor its execution. In a similar manner, software agents will also monitor product availability and send the products back to the appropriate requestor, as well as any other entities (consumers) that need to receive the information product. This tailored information-transfer occurs transparently to the user and should be accomplished with minimal computational resources (i.e., bandwidth and CPU).

Current operational procedures generally result in minimal pairings between the requesting entities and the sensor platforms. If redundant or near-redundant requests are made, little effort (if any) is made to couple them with similar requests. This inefficiency can be overcome by generating maximal pairings between the requesting entities and the sensor platforms. That is, a sensor platform may be able to accommodate multiple requests either concurrently or with slight modifications during the process of its overall mission.

Scheduling operations for a network of sensors is an NP-hard optimization problem. This resource allocation task is further complicated by the inclusion of a multitude of constraints in both the temporal and functional domains. A global optimization approach was proposed for solving this task-scheduling problem. This approach relied largely on evolutionary search methods but also took advantage of local search techniques by using common-sense reasoning where the problem can be partitioned to expedite the search. The task-scheduling problem was formulated as a nonlinear programming problem where the constraints were incorporated via penalty methods. Using penalty terms in the objective function will ensure that solutions are generated in light of conflicting requirements that can render the solution space infeasible. It is desired to expedite the search engine using a complementary technology, case-based reasoning (CBR), to generate candidate solutions from similar scenarios. The application of CBR to the STO implies that a CBR representation and metric must be defined for the operational environment to ascertain measures of similarity. The combination of the complementary CBR+expert systems (ES) technologies will be critical to accommodate short timeline requirements to generate maximal STO task pairings.

MAJOR RESULTS

We developed and performed initial evaluation of the evolutionary optimizer that will continually evaluate the status of the organic platforms underway and made recommendations regarding the sensor-to-target allocations. This decision tool incorporates aspects of situation and risk assessment in the objective function. The output from a simple CBR tool was integrated to achieve functionality, even though the tool was still in the development stage and had a very limited database of scenarios. We researched, defined, and outlined an object environment instantiated toward real-world sensor platform requirements. The abstract model details corollaries within the time-sensitive and dynamic operational environment. It is the opinion of this investigator that the matter of software agency

should be re-addressed given the advent of distributed computing models supported by Java, Corba, and other similar programming models.

NAVY RELEVANCE

The ability to optimally allocate sensor platforms in real time is in the critical path of Time Critical Strike and Theatre Area Missile Defense Future Naval Capabilities (FNCs). Dynamic sensor tasking provides the Battlegroup Commander with operational flexibility to react to a rapidly changing battle-space and maintain support for the timing and tempo of planned operations. This operational flexibility is enabled by the emergence of a "sensor grid" that is capable of operating in multiple modes based on its amenability to real-time tasking. Thus, the operational capabilities correspond directly to the sensor grid's ability to respond to either pre-planned or real-time tasking inputs.

Innovative Methods for Alertness Management and Crew Workload Allocation

Dr. Steven A. Murray
D374, (619) 553–6450

The objective was to exhaustively examine a large set of physiology and performance data—collected under real-world conditions—to identify relationships between operator alertness and task-performance quality. The original experiment employed alertness measures collected immediately **before** *task performance, a predictive approach relatively unique in the research literature but essential to the goal of maintaining satisfactory task performance in most naval settings involving intermittent workload. Significant associations were found between heart rate and electroencephalographic (i.e., brain) signals, and we found two measures of cognitive efficiency: attention to subordinate tasks and a measure of short-term memory. Additionally, a pending examination of eye-blink frequency is expected to show a similar pattern. In the process of analyzing these data, new methods of signal conditioning were also developed that represent contributions to the literature of psychophysiological methods. These relationships will be exploited to develop models of expected crew-level performance aboard ship. We also hope to support small crew sizes through focused applications of adaptive automation and decision support by using real-time physiological signals as inputs.*

BACKGROUND

The Navy desires fewer people aboard ships as a means to reduce operating costs, but the success of a minimal-crewing policy depends on extracting maximum effectiveness from each crewmember in operations characterized by intermittent workload. Long periods of time spent with only sporadic stimulation, however, lead to lapses of alertness that can have critical consequences when competent action is required [1,2]. Alertness levels, therefore, must be measured and managed to ensure that no crewmember jeopardizes the viability of the ship at critical moments through fatigue, inattention, or confusion.

Adaptive automation is an engineering method that can support operator effectiveness through comprehensive task management of crewmembers, sensors, and weapons [3]. Such automation schemes, however, necessarily rely on a real-time determination of operator readiness in order to function properly. Of critical importance is the operator's decision-making capacity in the initial moments after a problem arises (e.g., system emergencies and potential attacks). Effective adaptive automation algorithms must, therefore, have some assessment of operator state *before* workload allocation decisions are implemented.

Recent experimental results, using real-time physiological measures [4], have shown several task performance consequences from fluctuations in operator state. The essential contribution of this effort was to demonstrate that operator performance for even protracted tasks could be largely determined by brief physiology measures taken just before workload is introduced (figure 1). This sequential perspective represents a unique approach in the human performance literature. Further examination and elaboration of these results is at the core of this ILIR effort to provide an important enabling technology for the design of automated human–machine systems for the Navy.
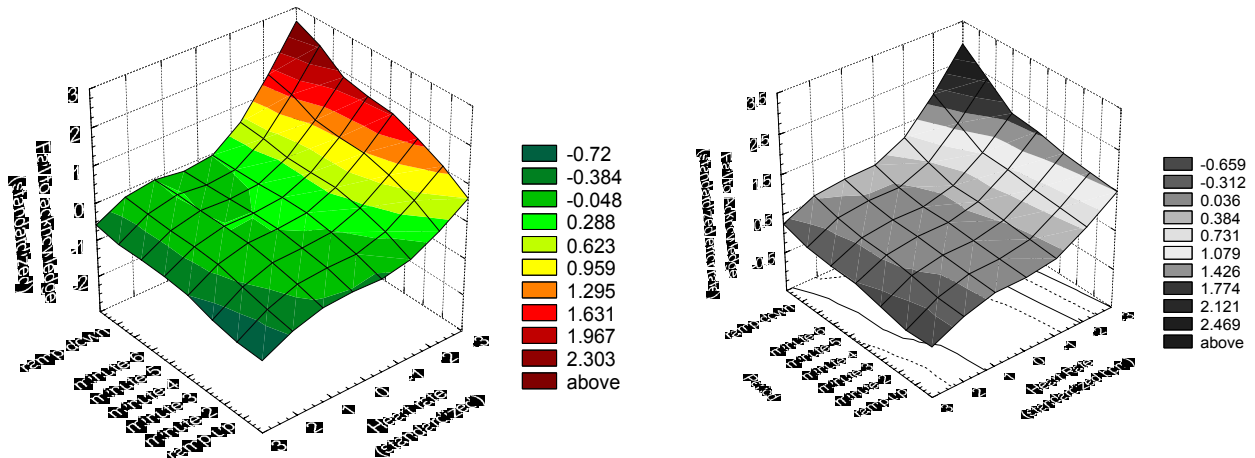
Figure 1. Alertness-performance effect for cardiac data. Reduced alertness is shown from left-to-right on the heart-rate scale; increasing error rates for a specific task are shown from bottom-to-top on the Fail-to-Acknowledge scale; and time duration of the task is shown from right-to-left on the Period scale.

OBJECTIVES

Objectives of this ILIR effort were to

- validate the original data set of human alertness indicators and to quantify their effects on human–computer task performance,
- extend this analysis to additional physiological indicators and task performance measures,
- develop a mathematical model of these effects relevant to the design of command and control systems, and
- confirm these effects in an operational setting.

APPROACH

This project realized its objectives through the following steps:

1. The signal processing and statistical analyses of the existing cardiac data were re-analyzed with more sophisticated statistical techniques.
2. Improved artifact rejection methods were applied to the EEG data, and the utility of these heart and brain measures were examined against multiple indices of performance to identify new predictive relationships.
3. Both SSC and university personnel developed a series of multidimensional models of these effects personnel. These results were prepared for publication and were used as foundation input to analytical models suitable for adaptive automation of human–machine systems.
4. Portable measurement equipment was identified, and an experiment was prepared to develop a new, independent data set collected under operational conditions. The methods developed by this ILIR project will be re-applied to these data to validate the modeling process and its predictive capabilities.

RESULTS

New predictive relationships have been identified between heart rate and EEG spectral power indices (i.e., normalized alpha, beta, and theta bands at three cranial sites) and two performance measures of general cognitive efficiency—attentiveness to subordinate tasks and a short-term memory task. While these general relationships had been expected from the research literature, this work represents a scientific advance in the following aspects:

- The relationships were found using physiological measures taken <u>before</u> task workload was imposed. This is a serial correlation, in contrast to the simultaneous correlations of most similar studies and, therefore, provides a predictive capability.
- These relationships were instantiated under "real world" conditions, i.e., in a free-running analog of shipboard watch-standing conditions; such realism is extremely rare in the research literature because data collection is so difficult, and effects are so easily masked.
- The foundation experiment provided an opportunity to compare multiple simultaneous physiological indices against the same performance measures; such data sets are virtually nonexistent in the research literature.

A project to model the alertness-performance effects from these data was initiated in cooperation with the University of Wisconsin Industrial Engineering Department during FY 00, and a report is expected shortly. In addition, an effort to apply Independent Components Analysis (another technique to extract artifact-free signals from noisy data) is still underway in collaboration with the University of California at San Diego (UCSD) Institute for Neural Computing.

A journal article concerning the cardiac results and an article concerning the combined cardiac/EEG indices are both being prepared. Furthermore, new data-reduction procedures were also developed in-house during FY 00 to generate artifact-free EEG and ocular (eye-blink) signals from the data set. These procedures represent the fruits of careful, methodical effort and compare very favorably with any such tools available in this field. In particular, eye-blink signals have been processed from facial muscle signals using a sensor ensemble not normally suited to this purpose. Two additional publications are planned to address these processing techniques. Recording equipment has been evaluated to allow ambulatory data collection from shipboard-watch personnel, and an experiment has been designed in consultation with the UCSD Neurosciences Department to support a study to gather equivalent data in a real (i.e., shipboard) or analog (e.g., training simulator) environment. Finally, discussions have begun regarding transitions of this project to current command and control acquisition programs.

NAVAL SIGNIFICANCE

This project is involved in developing quantitative models of human alertness and performance in operational human–machine tasks, based on unobtrusive physiological measures. The goals of this project are to support manning reductions while ensuring effective combat performance through knowledge and exploitation of real-time human capabilities.

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Knowledge Mining for Command and Control

Dr. Stuart H. Rubin
D73C, (619) 553–3554

This project investigated the use of data mining and related technologies (1) for insertion into existing naval technical projects and (2) for use in new technologies for an artificial-intelligence tool. For existing technologies, we selected and deployed commercial-off-the-shelf (COTS) mining tools (e.g., WizRule and WizWhy from WizSoft) to test the generation and impact of features upon the quality of the mined output. For new technologies, we custom-programmed a unique type of object-oriented expert system. Major results to date include the specification of a classifying radar system, which mines intelligence, surveillance, and reconnaissance (ISAR) data to dynamically predict the classification and likelihood of radar contacts. A second major result was a dynamically adaptive antenna design that uses a grammar-based genetic algorithm to rapidly reconfigure a millimeter antenna realized in a three-dimensional (3-D) polysilicon chip configuration. We believe that the radar classification system can be easily extended to sonar echo-location and mapping systems. The dynamically reconfigurable antenna extends to evolutionary hardware design. Present work on creative object-oriented expert systems may hold even more promise if break-even can be exceeded (i.e., the system learns more essentially correct knowledge than it is given).

This project investigated the use of data mining and related technologies (1) for insertion into existing naval technical projects and (2) for use in new technologies for an artificial-intelligence tool. For existing technologies, we selected and deployed commercial-off-the-shelf (COTS) mining tools (e.g., WizRule and WizWhy from WizSoft) to test the generation and impact of features upon the quality of the mined output. For new technologies, we custom-programmed a unique type of object-oriented expert system. Here, the subclasses were mined with the knowledge engineer in the loop. The result promises to be an expert system, capable of learning "more" than it is taught, capable of deductive and inductive reasoning as dynamically determined to be appropriate, capable of stochastic inference, and unlike conventional expert systems, capable of polymorphic (e.g., analogical) reasoning. Major results to date include the specification of a classifying radar system that mines intelligence, surveillance, and reconnaissance (ISAR) data to dynamically predict the classification and likelihood of radar contacts in real time. Unlike traditional rule-based systems, this system is capable of learning from simulations, thus making it far less costly to train and maintain. Also, conflicting rules cannot occur by definition of the mining mechanism. A second major result was a dynamically adaptive antenna design that uses a grammar-based genetic algorithm to rapidly reconfigure a millimeter antenna realized in a 3-D polysilicon chip configuration. Such an antenna is more capable of frequency hopping and positional invariance with respect to signal strength than was previously possible. We believe that the radar classification system can be easily extended to sonar echo-location and mapping systems and that the dynamically reconfigurable antenna extends to evolutionary hardware design. These techniques are clearly of potential naval significance.

The specific goal of this project was to discover, explain, disseminate, and prototype the most efficient methodologies for increasing the use of databases by effectively refining them into knowledge

bases. This has increased and will continue to increase our understanding of the role of heuristics in knowledge discovery and will emphasize the need to decrease the cognitive burden on the knowledge engineer in cracking the knowledge, feature, and generalization-acquisition "bottlenecks"— evidencing the inadequacy of meta-rule models for learning. Indeed, cracking the knowledge-acquisition bottleneck [1, 2] has been widely recognized as the key to unlocking the potential for constructing large-scale, intelligent, decision-support systems.

Nils Nilsson at Stanford University [3] was perhaps first to recognize the role of heuristics and features in the design of his A* algorithm and the exemplary solution of the 15-puzzle. Ross Quinlan [4] reported on the complexity of the feature extraction problem for the domain of chess. He reported that the extraction of cogent features improved one's game considerably, but at an empirical cost of one workman month per feature (see also [1]). Similarly, Tom Mitchell et al. [5] explored the use of Explanation-Based Learning (EBL) for generalizing features from single examples. Professor Mark Embrechts [6], whom we brought to SSC San Diego to give a research lecture on the topic of data mining in the pharmaceutical industry, emphasized his use of genetic algorithms and neural networks for extracting features from bio-pharmaceutical compounds for rational drug design, as well as for military planning. Furthermore, we have written LISP code [7] that will synthesize small programs from exemplary input/output (I/O) behavior and embedded operational constraints.

This project necessarily required a two-step approach. First, our theoretical framework needed to be extended to incorporate certain features [8, 9]. Second, an implementation had to be realized in accordance with the dictates of Gödel's Incompleteness Theorem [10]. The theorem applies because, in FY 01, we will mine knowledge from knowledge, which conditions the knowledge with salient features that, in turn, improve the mining process (i.e., self-reference). To clarify, one could say that the implementation represents one among a denumerable set of competing recursively enumerable, yet not recursive, theories.

Today, expert systems are the cutting-edge technology for back-end (i.e., symbolic) intelligence. Such systems can be hybridized with front-end neural net sensors, genetic algorithms, and even case-based learners. However, in the final analysis, the expert or rule-based system best captures how we learn and symbolically reason. Expert systems represent the state of the world with a context (e.g., the ship is under missile attack). The context is then matched against a base of rules to see what action to take. The most specific rule is applied in the event of a tie. Rules are expressed in the form: situation → action. The acquisition of rules corrects errors. There is one correction for each rule acquired. This is linear learning. It is the best that can be achieved using conventional symbolic learning technologies.

Knowledge mining, as we define it, offers the possibility of nonlinear learning. For each quanta of knowledge acquired by the system, more knowledge will be automatically induced. This enables the construction of an intelligent system, which will be creative, fail-soft, can learn over a network, and otherwise has enormous potential for automated decision-making. Knowledge mining is based on context-free grammars, which underpin compilers for all modern high-level programming languages. The demonstration will be based on two grammars—one for situations and one for actions with inter-action between the two. The demo will allow the user to (verbally) teach or otherwise communicate with the system through a succession of extensible pull-down menus. An object-oriented approach will relate conceptual entities. For example, quicksand is an instance of sand that inherits all the

properties of sand and adds a few more. The grammatical basis will enable the system to make successive hierarchical transformations. This will be demonstrated in the context of the prototype's capability for learning concepts in natural language. In short, the prototype will exhibit creativity as an emergent, as opposed to programmed, property. This differentiates it from projects such as Cyclopedic Knowledge Base (CYC), which is sponsored by the MCC Texas Consortium.

Unlike conventional expert systems, intelligent systems based on knowledge mining embed an extensible capability for learning based on the grammatical representation and transformational approach to consequent generation. Such intelligent systems do not fail hard when presented with previously untrained situations, as do conventional symbolic systems. Rather, intelligent systems based on knowledge mining fail soft and are capable of rendering human-like judgments with explanations upon request. These systems operate at near natural-language levels and, thus, are capable of readily capturing complex situations and actions through interaction with a knowledge engineer. The need to use the less-powerful, case-based reasoning technologies is, therefore, minimized. Intelligent systems based on knowledge mining will propagate any changes in ground truth, which makes truth maintenance far more effective here than possible in conventional expert systems. Fuzzy set theory may be applied to allow for qualitative and quantitative fuzzy logics. For example, an embedded qualitative description of a vehicle may be "ship-like" as well as "plane-like" (e.g., an amphibious aircraft).

In FY 01, a software prototype will be custom-programmed in Visual Basic Professional 6.0. The prototype will demonstrate a symbolic learning capability not to be found in any commercial expert system or applied theory to date. It is argued that the intelligent components of any Command Center of the Future (CCOF) cannot be realized in the absence of a strong capability for symbolic learning. The software prototype will not only serve to demonstrate this capability, but will also apply it in the context of selecting a beach-landing site. The envisioned prototype will be a decision support system capable of reasoning from user-defined phrases expressed in natural language. The specific objectives of this prototypical demonstration, in the context of the beach-landing site domain, are to (1) demonstrate a strong capability for symbolic learning; (2) demonstrate an accelerating capability to learn; (3) demonstrate conversational learning (i.e., learning by asking appropriate questions); (4) demonstrate a metaphorical explanation subsystem; (5) demonstrate probabilistically ranked alternative courses of action that can be fused to arrive at a consensus that is less sensitive to occasional errors in training; and (6) demonstrate a capability to enunciate responses. Note that speech-recognition software is front-end COTS. This intelligent system, unlike conventional expert systems, is polymorphic—enabling its semantics to be networked. This makes possible a very scalable architectural design. Such a system can front-end a natural-language interface to the extensible object-oriented pull-down menus.

The plan of action and milestones are to (1) complete the on-going design of the system on paper (first iteration was completed October 2000); (2) implement the design by July 2001 through the employment of new professionals (NPs) and/or other professional programmers; and (3) populate the CCOF knowledge base by September 2001. The custom-programmed software will be demonstrated at the end of FY 01. Figure 1 is a flowchart of the proposed intelligent network subsystem.

Figure 1. An intelligent network subsystem.

Virtual Rule Base

Situation Grammar (S)

Blackboard of disjuncts in nondeterministic reduction parse of (S) provides context for expansion of (A), ..., (A')

Most-Specific Virtual Rule Fired?

Yes

Erroneous Result?

Yes

Truth Maintenance: Trace error to grammar production(s)

Specify new (increased) context. The closer to primitive the level of adjustment, the more that is learned in (S). Conversely, the higher the level of adjustment, the more that is learned in (A), ..., (A').

The virtual rule space is increased. Adjust stochastics and fuzzy functions.

Fuse alternative actions by qualitatively fuzzy match in (A), ..., (A') to minimize error.

Intelligent Network Subsystem

Effect (creative) action, which may ask a question(s).

Pass control to OS

Context specified or changed?

Yes

Randomize context (if necessary) and post to bulletin board.

Figure 1. An intelligent network subsystem (continued).

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[*] For further information, contact author.

Deduction, Estimation, and Prediction of Events via a New Approach to Second-Order Probability with Applications to Decision-Making in C4I Systems

Dr. I. R. Goodman, D44215, (619) 553–4014
Dr. Donald Bamber, D44215, (619) 553–9219
Dr. H. T. Nguyen, New Mexico State University, Navy American Society for Engineering Education (ASEE) Summer Fellow

This research sought to develop a sound, unified, and computer-efficient way to model rule-based systems treating typical naval-oriented data-fusion problems. Such problems often involve conditional or unconditional premises and conclusions, based on stochastic or linguistic information. Frequently, the premise information is only partially specified via unconditional or conditional probability thresholds. The approach taken was through the novel framework of a Second-Order Probability Inference System (SOPIS), an extension of the preliminary FY 99 Second-Order Probability Logic (SOPL). Together with SOPL, three other mathematical tools (previously developed by the Principal Investigator and Professor H. T. Nguyen, New Mexico State University) were also used to form SOPIS. Chief results obtained during FY 00 included (1) significant improvement in implementation of the unity-limiting probability threshold form of SOPIS; (2) widening of the scope of the fixed, non-unity-limiting probability threshold form of SOPIS; (3) establishment of a preliminary approach to modeling stochastic- and linguistic-based rules depending on population characteristics; and (4) derivation of a major breakthrough producing a near optimal solution to the modeling problem and also having a significantly reduced computational complexity.

From a general structural viewpoint, the basic decision issues that the Navy faces in data fusion are quite similar to the fundamental real-world quandaries individuals face day-to-day. Such issues involve decision-making within an uncertain environment, often requiring the use of inference rules, consisting of well-delineated premises and conclusions. However, both premises and conclusions are, in general, masked by uncertainties that may be modeled by unconditional and conditional probabilities. (See [1], part 3 for details of such modeling.) Alternatively, when a linguistic-based perspective is employed, such rules may be modeled more naturally in terms of possibility, or fuzzy set membership functions, and possibilistic or fuzzy logic operations and relations. (See [2] for examples of such modeling.) In addition, typically only partial knowledge is present concerning the premise probabilities—either (a) in the form of specifying only lower threshold probabilities or possibilities or (b) in qualitative form, whereby the probabilities (or possibilities) are specified as being close to (but not necessarily) unity. For example, either in a military or civilian context, one may be faced with the *transitivity problem* involving three events, a, b, c (such as a = "enemy will attack tomorrow," b = "enemy has moved 100,000 troops to border area," c = "political situation has not improved." What is the conclusion conditional probability P(a|c), when we only know—or worse, can only "guesstimate" or put lower bounds on the premise conditional probabilities P(a|b), P(b|c)? While this problem in a nonprobability context reduces to the classical *Barbara* syllogism problem (in fact, referring back to Aristotle—see [3] for a history of the classical problem and related issues), in its probability form with uncertainties introduced through the above conditional probabilities, a

"discontinuity" occurs in that the problem does *not* yield a simple solution analogous to the classical counterpart: When the premise {"if b, then a," "if c, then b"} holds, then so must the conclusion "if c, then a" hold true. That is, we should expect that as the premise probabilities are degraded from a perfect unity level, so should (in some reasonable sense) the conclusion probability $P(a|c)$ be gradually reduced from the unity level. In addition, it should be noted that the classical logic operator corresponding to "if (.), then (..)," called the "material conditional," is *not at all* compatible with the naturally corresponding conditional probability value $P(.. |.)$. (See [1], part 3; [4]; and [5], chapters 0 and 1 for more details of the disparity between using the seemingly natural material conditional operator for if–then statements at the algebraic or logical level and the corresponding semantic/ probabilistic evaluation level vs. conditional probability.) In a probability context, one can design situations where the corresponding premise conditional probability counterparts $P(a|b)$, $P(b|c)$ can both be quite close to unity (but both not exactly unity), yet the conclusion conditional probability counterpart $P(a|c)$ can be high, moderate, or even zero! Yet, if we consider "situations at random" and in an intuitive manner "average things out," most of the time when $P(a|b)$, $P(b|c)$ are reasonably high, so must be $P(a|c)$.

From extensive literature surveys, one can conclude that in applying rule-based systems to military or civilian data-fusion problems, approximately, six directions of action have been followed up to now: (1) One simply ignores the fact that the rules are not perfect and just proceeds with reasoning as if the classical logic case [6] were valid; (2) One introduces "ad hockery" to manipulate and evaluate the rules, as in the form of "certainty" factors [7]; (3) One forms a formal system where transitivity is forced—or formally assumed—to hold always; (4) One considers a system where, explicitly, it turns out that transitivity does not hold, although other desirable properties may well hold in its place as in the work of Adams [8, 9]; (5) One considers various reformulations or restrictions of the original problem, such as assuming the premise conditional probability thresholds are made to approach (but not equal) unity [10] or utilizing "rational closure" [11] or maximal entropy considerations [12]; (6) one "fuzzifies" the classical logic material conditional operator or introduces a somewhat similar-appearing operator. (See [13] for background.) This issue, in particular, has plagued the artificial intelligence community for 30 years concerning approaches (1) to (5), since the latter seek ways to extend classical logic reasoning to a real-world format. (See Pearl [14], various sections, for discussions on this and related issues.) In addition, the transitivity problem has produced controversy within the fuzzy logic community, although founder L. A. Zadeh and others claim approach (4) is sufficient [15]. (For criticism of this argument and a preliminary phase of a corresponding approach within a conditional probability context, see Goodman & Nguyen [16].) However, none of the above approaches considers the more natural approach of simply randomizing—in either a uniform or more general way (such as via the Dirichlet distribution)—the probabilities themselves and *proving, with no additional assumption,* that indeed, in a fully rigorous and implementable sense, the quantitative threshold problem is fully solvable, compatible with commonsense reasoning, i.e., when $P(a|b) = s$, $P(b|c) = t$, for any given s, t between 0.5 and 1, the *averaged value* of $P(a|c)$, relative to P varying randomly and the above premise constraints, is a completely computable function of s, t, which is somewhat less than the product of s and t and approaches unity as s, t are made to approach unity. (See [17] for more details.) This technique is a special application of the use of *second-order probability theory* or the theory of "probabilities of probabilities," a little-used area of probability best illustrated by the previous efforts of Aitchison [18], followed by an application to a particular updating problem [19].

The above example of transitivity is a simple illustration of the surprisingly deep issues involved in extending classical logic techniques to those treating "probability logic." This certainly holds for other seemingly simple schemes used in rule-based systems formulable in classical logic (as valid or invalid), such as *contraposition*, *strengthening*, *induction*, *abduction*, *right- and left-hand cuts*, etc. (See again, e.g., [6], [14].) FY 99 Second-Order Probability Logic (SOPL) was initiated, based on both the successful solution to the transitivity problem by the Principal Investigator (PI) and Prof. H. T. Nguyen (New Mexico State University) (see [17]) and the independent, equally successful, work of the co-PI (D. Bamber, Code D44215) in also using second-order probability to solve for the qualitative or unity limiting-premise probability threshold case, not only the transitivity problem, but the general probability deduction problem [20]. It should be noted that Bamber's results coincide essentially with that of [10], [11] derived from a rather different (and apparently more complicated) viewpoint.

In FY 00, the above work was greatly extended in both the qualitative and quantitative (or fixed) threshold directions. In the qualitative direction, it was finally established—in a new, more elegant, formulation of Bamber's original result [20]—that a natural use of the material implication operator can be applied to the generic algorithm characterizing the general solution to the qualitative aspect of probabilistic deduction [21]. Additional insights into the qualitative approach were presented in [22], section 7 and explained in the invited presentations by Bamber [23–25]. In the quantitative aspect of the problem, a significant extension of premise–conclusion pairs was accomplished (see [27, 28] for preliminary results with full documentation presented in [29, 30]). These results used, in addition to refined second-order probability techniques—including surface integral procedures [29]—two previous mathematical tools developed by the PI and Prof. Nguyen as part of past ILIR programs at SSC San Diego: *conditional event algebra* (CEA) [30], used to model and logically manipulate expressions compatible with conditional probabilities and *one-point random set coverage* (OPRSC) [31], homomorphic-like representations of fuzzy logic via probability theory in both static and dynamic forms interpreting linguistic-based information. In particular, use of CEA and OPRSC led to a general basis for modeling and evaluating inference rules based on the characteristics of populations [32] (extending preliminary results in [13]) and thus provided a direct challenge to Zadeh's pure fuzzy logic approach (see direction of action (4) above). This also employed—to a lesser extent—use of OPRSC and (replacing CEA) *relational event algebra* (REA) (see [1], part 3 for a review) used to model and manipulate expressions compatible with various designated functions of probabilities, and hence, including CEA as a special, but important, subcase where the functional form is arithmetic division.

The most significant result obtained during FY 00—and a partial basis for the FY 01 proposal—was the derivation of a near optimal solution to the modeling problem with a significantly reduced computational complexity ([19], section 6). More specifically, it was shown that for a large class of inference rules, in effect, the premise set of conditional probabilities could be reduced (for thresholds sufficiently close to unity) to a single conditional probability (and hence, a single threshold). In turn, this not only produces a much less complicated problem, but also yields a relatively simple closed-form solution, under a general Dirichlet prior assumption. The foundation for direct applications of the above results to a general sensor-fusion scenario involving both kinematic and nonkinematic attribute matching of track histories is being carried out at the time of this report [33]. Two byproducts of the ongoing work in modeling rule-based systems via second-order probability techniques

have been some new general results in approximating Boolean-like operators [34] and a multivalued logic [35] with applications to decision-making.

Also, during FY 00, significant advances were made in establishing bases for further work in three related areas of decision-making involving incompletely specified probabilities:

1. Robustness of conclusions: Consider the following example [20, p. 28, ex. II]. Suppose we are given the rules "If b, then a" and "If c, then not a" and it is known that $P(a|b) \geq 1-\varepsilon_1$ and $P(not(a)|c) \geq 1-\varepsilon_2$. When b and c both hold, what can we conclude about the likelihood of a? The answer depends on the relative sizes of the epsilons. Thus, if $\varepsilon_1 = \varepsilon_2$, then nothing can be concluded about the value of $P(a \mid b\&c)$. However, if $\varepsilon_1 = (\varepsilon_2)^2$, then it may be concluded that, on average, $P(a \mid b\&c)$ is close to one. Thus, in the qualitative aspect of SOPIS, our conclusions depend on what we know or are willing to assume about the relative sizes of the epsilons associated with each rule. The most robust conclusions that we can reach are those for which no assumptions or knowledge of relative sizes of epsilons are needed. In FY 00, an algorithm for finding these most robust conclusions was developed [21]

2. Causal reasoning: A method was developed [36] for adding additional nodes and arcs to standard Bayes nets to enable these tools to be used for inferring the effects of causal manipulations upon variables of two types: (a) Variables whose values before the manipulation were unknown. (b) Variables whose values before the manipulation were known (but which might change). (These two types of variables must not be treated equivalently, which appears to have been done in at least one commercial product.)

3. Alternative approach to rule-based reasoning via use of data directly. The main idea here is a judicious application of the well-known—but rarely employed—fundamental existence theorem of linear regression in tandem with standard statistics estimating means and covariance matrices [37].

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[*] For further information, contact author.

Communications

Telesonar Channel Models

Paul A. Baxley, D857, (619) 553–5634, co-principal investigator
Joseph A. Rice, D857, (619) 553–3107, co-principal investigator
Dr. Homer P. Bucker, D857, (619) 553–3093, co-investigator
Vincent McDonald, D857, (619) 553–3094, co-investigator
Associates: Professors John Proakis and Milica Stojanovic, Northeastern University;
Professor Michael Porter, New Jersey Institute of Technology; Dale Green, Benthos, Inc.

The objective of this research project was to understand undersea acoustic communication channels via theoretical and numerical modeling of the propagation physics. A physics-based numerical propagation model that includes the effects of multipath spread and Doppler spread was developed as a prediction and analysis tool for underwater acoustic communication problems. The model used three-dimensional Gaussian beams and quadrature detection to obtain the channel response for finite-duration constant-wavelength tones. By using a very short pulse, the output of the quadrature detector provided an estimate of the channel impulse response, which may be used to determine the multipath spread. In addition, the Doppler shifts associated with source/receiver motion can be accumulated for the individual beams, providing Doppler spread. The model was productively used in experiment planning and channel data analysis for several telesonar sea tests. Agreement between the modeled and measured data was, in general, very good. A statistics-based, real-time channel emulator has also been developed. Additionally, we investigated the effectiveness of various beam-tracing algorithms. The use of the physics-based impulse-response predictions with the emulator provides a powerful tool for testing and developing of underwater acoustic modems and sonar systems.

BACKGROUND

Telesonar is undersea acoustic signaling for data telemetry, wireless networks, remote control, feedback links, ranging, and beaconing. Telesonar technology incorporates modern digital signal processors (DSPs) and digital communications theory to combat deleterious aspects of the physical channel and to exploit advantageous channel features. Acoustic communication signals propagating through a shallow-water environment may be adversely affected by the phenomena of multipath spread and Doppler spread, as illustrated in figure 1. The multipath spread is caused by the complex multipath propagation characteristic of shallow-water waveguides, including such effects as refraction, multiple reflections from boundaries, and scattering from inhomogeneities. The Doppler spread results from the time-variability of the acoustic medium, arising primarily from source/receiver motion or surface boundary motion. These phenomena can significantly disperse and distort the signal as it propagates through the channel. A numerical propagation model that simulates these effects is desired for the systematic study of these phenomena. Such a model is also a useful tool for environment-dependence assessment, performance prediction, and mission planning of telesonar systems.
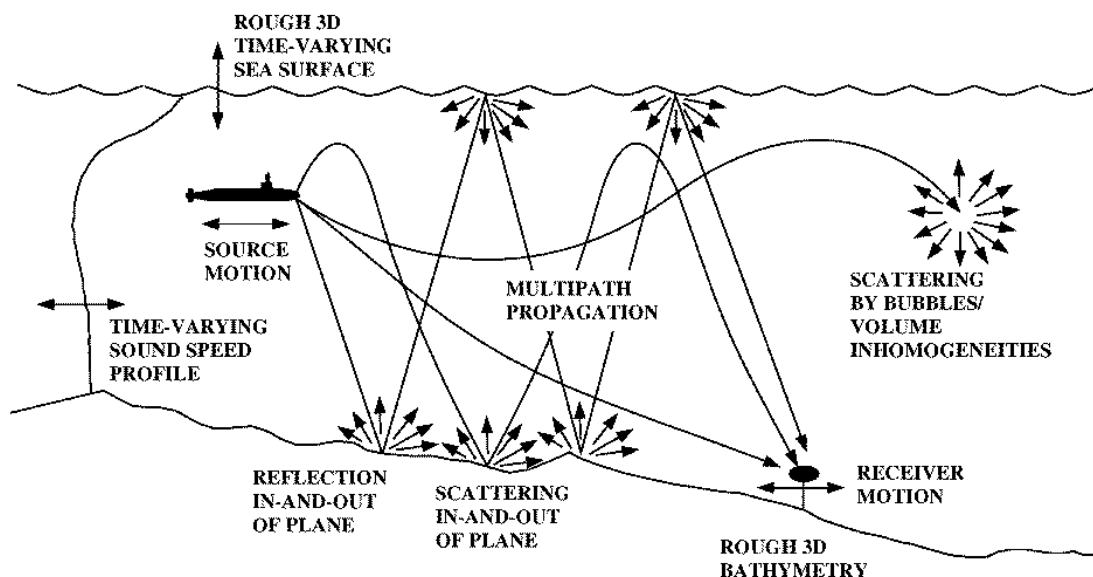
Figure 1. Important physical processes affecting underwater acoustic communications signals.

TELESONAR CHANNEL MODEL

The objective of this work is to understand undersea acoustic communication channels via theoretical and numerical modeling of the propagation physics. A physics-based numerical propagation model that includes the effects of multipath spread and Doppler spread has been developed as a prediction and analysis tool for underwater acoustic communication problems. The 3-D Gaussian Beam/ Quadrature Detector (3DGBQD) modeling approach [1] is to trace, in three dimensions, closely spaced microbeams of a finite-duration, continuous wave (CW) pulse from source to receiver, accumulating travel-time, level, phase-shift, and Doppler-shift information for each microbeam. This information is used to construct the QD (an analog of the discrete Fourier transform) response for each microbeam. The QD response provides a prediction of the levels and arrival times associated with the various propagation paths from the source to the receiver. The total QD response is then obtained by summing the QD responses of all component microbeams. By using a very short pulse, the output of the quadrature detector represents an estimate of the channel impulse response, which may be used to determine the multipath spread. Three-dimensional Gaussian beam tracing [2] is used so that out-of-plane reflections from rough surfaces or sloping bathymetry can be adequately modeled. The use of a dense fan of Gaussian microbeams allows direct modeling of scattering from arbitrarily rough surfaces. Currently, the model includes multipath spread associated with the propagation through a refractive medium and the reflection and scattering of energy from an arbitrarily rough, three-dimensional seafloor. Doppler spread resulting from source/receiver motion is included at present, and future implementations will include the effects of a time-varying sea surface.

A time-dependent Markov simulation [3] developed by Dale Green of Benthos, Inc., in association with this project, but under independent ONR sponsorship, is currently operational and has been used to simulate the performance of several underwater communications channels. Modeled impulse responses obtained by the 3DGBQD model are supplied as input to this statistics-based, real-time

channel emulator. The use of realistic, physics-based, impulse-response predictions in conjunction with the emulator has greatly augmented at-sea data for the testing and development of underwater acoustic modems and sonar systems.

The 3DGBQD model has been successfully used to predict multipath spread, thus aiding in the design of recent experimental configurations for telesonar applications. Sublink 2000, conducted in 200-m water near San Diego, demonstrated real-time digital acoustic communications between a submerged submarine, a surface ship, bottom-mounted instrumentation packages, and gateway communication buoys. The feasibility of delivering data from commercial oceanographic sensors to shore was demonstrated in Seaweb 2000, conducted in roughly 10-m water in Buzzards Bay, Massachusetts. Another undersea network was deployed during the second Front-Resolving Observational Network with Telemetry (FRONT) experiment, with the objective of delivering current profile data for the study of ocean fronts on the inner continental shelf (20- to 60-m water depth, near Long Island Sound). The SignalEx 2000 experiments were conducted in conjunction with the above experiments, with the objective of correlating acoustic signaling performance to channel characteristics. For all of these experiments, 3DGBQD model predictions were used to determine optimal source/receiver configurations and to ascertain when the effects of a rough sea surface or variable bathymetry could degrade performance. In most cases, simulated impulse responses agreed well with measured impulse responses, although loss assumptions had to be adjusted because of inadequate knowledge of bottom properties.

GAUSSIAN BEAM TRACING

Gaussian beam tracing is a ray-based method of acoustic wave propagation that overcomes some of the implementation problems of conventional ray methods. By approximating a given source by a fan of Gaussian beams which propagate through the medium according to the standard ray equations, the field at any given point can be constructed by adding up the contribution from each beam at that point. Eigenray computations, perfect shadows, and infinite caustics associated with standard ray methods are thereby eliminated, and the applicability to lower frequency problems is improved.

There are four approaches to the Gaussian beam tracing method currently being applied to the ocean acoustics problem. While superficially similar, they differ mainly in the type of beam distribution used (Gaussian or triangle) and the manner in which beam spreading is handled. The most rigorous method is that of Porter and Bucker [4], which is based on the seismological work of Cerveny et al. [5]. Gaussian beam spreading is governed by a pair of differential equations that are integrated along with the standard ray equations. Bucker [6] provides a simpler approach, termed Simple Gaussian Beams (SGB), in which the beam-width expands in proportion to the arc length of the beam path. Porter [7] later used the beam construct to develop Geometric Beam Tracing (GBT), which uses the Cerveny beam equations to calculate the spreading of the ray tube. GBT replaces the Gaussian distribution with a triangle function, with the beam influence decreasing from its maximum at the center ray to zero at the adjacent rays. The result is a model that precisely recovers the ray-theoretic result. Weinberg and Keenan [8] introduced the similar concept of Gaussian Ray Bundles (GRBs), but with an additional feature that limits the beam focusing such that simple caustics are handled accurately. Without these limits, GRB and GBT are essentially the same, except for beam distribution used. Both the SGB and Cerveny methods require certain parameters to be set (e.g., the starting conditions of the

beams) to run the models. Such parameters are not required for the GBT and GRB approaches, thereby creating an obvious advantage.

The merits and drawbacks of each approach were examined by casting each technique within the same theoretical framework and by comparing predictions obtained by these methods with each other and a reference solution (normal modes) for several test environments, including the Sublink 2000 site. All algorithms agreed well enough with the reference solution to warrant their use in practical applications. The GBT and GRB methods possess the important advantage of not requiring certain parameters to be set before execution. The beam-focusing limits with the GRB method provide useful means of handling caustics.

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Wireless Network Resource Allocation with QoS Guarantees

Stephan K. Lapic
D822, (619) 553–3073

We developed resource-allocation mechanisms for wireless networks that are optimal with respect to Quality of Service (QoS) objectives. The methods developed rely on techniques from network calculus and employ a novel approach to address resource sharing. The methods are applied to the case where the arriving traffic and service mechanisms have deterministic descriptions, as opposed to stochastic ones. An example is presented. Results show that the methods obtained work well for heavily loaded networks where traditional resource-allocation schemes may fail. The methods appear to be less effective for lightly loaded networks, indicating that generalizations are warranted.

SUMMARY

Data communication networks in both military and commercial venues are increasingly employing packet-switched technologies; the most widespread among these is Internet Protocol (IP). Packet-switched networks use resources much more efficiently than more traditional circuit-switched networks. In the military, this need for efficiency is reflected in the move away from dedicated "stove-piped" systems toward more general, multi-purpose data transport networks. However, this increased efficiency comes at the price of increased variability in system performance. In packet-switched networks, data loss and random delivery delay are inevitable and controlling these becomes an issue of paramount importance.

The need to provide predictable performance in the presence of efficient resource sharing has motivated the development of quality of service (QoS) mechanisms. There are a number of fundamental QoS parameters: delivery delay, delay variation, data loss, and throughput among them. A QoS-capable network can differentiate traffic according to its delivery requirements and provide intelligent resource allocation that attempts to satisfy those requirements.

The need for QoS is all the more pronounced in wireless networks. In military wireless networks, resources (e.g., bandwidth) may be tightly constrained, the potential for conflict is greater than in wired networks (since radio is inherently a broadcast media), and the types of traffic that must be carried may vary widely. Several networks in use or development by the Navy and Marine Corps are wireless or have a significant wireless component; such networks include the Naval Gunfire Support Network, the Joint Tactical Radio System, the Extending the Littoral Battlespace (ELB) demonstration backbone network, and Link 16.

In this work, we consider a wireless network with an arbitrary but fixed topology. We suppose that time is divided into discrete slots with each transmitting node capable of sending one fixed-size data packet per slot. A collection of (source, destination) pairs is specified, as is the fixed route from each source i to each destination k. This induces a collection of (source, relay, destination) triples (i, j, k) as j varies along the path from source i to destination k.

The flow of traffic in the network can be characterized by using network calculus. To be concrete, let $A_{ik}(t)$ denote the number of packets generated at source i by time t with destination k, and let $X_{ik}(t)$ denote the number of (i, j, k) packets that are *capable* of receiving service at node j by time t. Then, the number of packets that have arrived at node k from source i by time t is given by

$$B_{ik}(t) = \min_{0 \le s \le t} [A_{ik}(s) + X_{ik}(s,t]] \tag{1}$$

where $X_{ik}(s,t] \equiv \min_{s=s_0 \le s_1 \le \cdots \le s_L = t} \Sigma_{m=1}^{L}(X_{ij_{m-1}k}(s_m) - X_{ij_{m-1}k}(s_{m-1}))$ if $i = j_0 \to j_1 \to \cdots \to j_L = k$ is the path from i to k. When bounds on the amount of arriving data traffic and available service are provided, (1) can be used to obtain bounds on the number of packets queued in the network and the delivery delay experienced by those packets.

Of course, not all traffic can be successfully transmitted in a wireless network at the same time. We assume that each node has a single-channel, half-duplex radio. Since a single radio can transmit at most one packet per time slot, receive at most one packet per time slot, and cannot simultaneously transmit and receive, conflicts are created within the collection of (source, relay, destination) triples (i, j, k). Also, conflicts arise when transmissions from two nodes collide at a common neighbor, even if that neighbor was not the intended recipient of both transmissions.

A set of triples is *independent* if no two of its members conflict. The set of triples that receives service in any time slot is clearly independent. An independent set is *maximal* if it is not strictly contained in some larger independent set. Letting $M_1, M_2, \ldots, M_q$ denote the maximal independent sets, the scheduling problem for the radio network is to, in each time slot, pick a maximal independent set M_p. All triples in M_p will then be allowed to transmit their traffic during that time slot. We wish to choose the sets M_p in an intelligent way.

Accomplishing this requires bounds on the amount of arriving traffic as well as a characterization of the service to be provided the traffic. Specifically, we assume that the arriving traffic has a linear envelope so that $A_{ik}(t) - A_{ik}(s) \le \sigma_{ik} + \rho_{ik}(t-s)$ for some nonnegative constants σ_{ik} and ρ_{ik}. Likewise, we suppose a linear lower bound on the amount of service provided each maximal independent set M_p. Specifically, we suppose the proportion of time that each M_p is picked in every time interval $(s,t]$ is bounded from below by $h_p(t-s) = \lambda_p(t-s) - \theta_p$ where λ_p and θ_p are nonnegative. Under these hypotheses, it can be shown that the number of packets with source i and destination k in the network at any time is bounded by $Q_{ik} \equiv \sigma_{ik} + \Theta_{ik}$ while the delays experienced by those packets is bounded by $d_{ik} \equiv \lceil (\sigma_{ik} + \Theta_{ik}) / \Lambda_{ik} \rceil$ with $\Lambda_{ik} \equiv \min_{1 \le m \le L} \Sigma_{p:(i,j_{m-1},k) \in M_p} \lambda_p$ and $\Theta_{ik} \equiv \Sigma_{m=1}^{L} \Sigma_{p:(i,j_{m-1},k) \in M_p} \theta_p$, provided $\Lambda_{ik} \ge \rho_{ik}$. Because the resources available are finite, we require that $\Sigma_{p=1}^{q} \lambda_p \le 1$. This fundamental constraint limits the service performance experienced by the network traffic.

These observations motivate a candidate objective function. The factors θ_p are needed to realize the continuous allocations $h_p(t-s) = \lambda_p(t-s)$ in discrete time, and the main factors are the bandwidths λ_p. Thus, for example, the delivery delays are approximately bounded by σ_{ik}/Λ_{ik}. Taking the weighted average of these approximate delay bounds yields the objective function

$$J = \Sigma_{i,k} \rho_{ik}(\sigma_{ik}/\Lambda_{ik}). \tag{2}$$

The prescribed optimization problem is to choose the λ_p to minimize J subject to the constraints that $\lambda_p \geq 0$ for all p, $\Sigma_{p=1}^q \lambda_p \leq 1$, and $\Lambda_{ik} \geq \rho_{ik}$ for all i and k. This objective function is not differentiable and the number q of free variables may be fairly large, but success with this optimization problem has been obtained using a modification of the gradient projection method.

To illustrate, we present an example. In the 10-node network of figure 1, nodes 1 through 5 are sources, and nodes 6 through 10 are destinations. With shortest path routing, the 5×5=25 (source, destination) pairs yield 46 triples. For the given topology, there are 225 maximal independent sets of triples. For each source i and destination k, we assume arrival processes of the form $A_{ik}(t) = \lfloor \sigma_{ik} + \rho_{ik} t \rfloor$ with $\sigma_{ik}=1$ and $\rho_{ik} = \rho$ variable. Figure 2 shows the average delivery delay observed in a 10,000 time-slot simulation as the load ρ is varied when the maximal independent set M_p are weighted with λ_p selected to minimize J as given in (2) above. Also shown in figure 2 are results from three more traditional time-slotted schedulers. Of these, the best results are obtained with a 40-slot frame. This is obtained by starting with one slot for each of the 46 triples and then obtaining a slight reduction in frame size due to the spatial re-use made possible by the network topology. In fact, at low to medium usage, this scheme outperforms the optimized scheme we have developed and described above. However, notice that the 40-slot scheme fails to operate as the aggregate arrival rate exceeds 0.625 packets/slot. The optimal scheme continues to function and give quite reasonable delay up to a load of 0.875. Moreover, the analysis described above shows that 0.875 is the maximal load for this network. No scheduler will be able to provide bounded delay at higher load values.

The results for high loads are very encouraging. Anecdotal evidence suggests that military networks are very often operated at or near capacity. However, the results for low loads are somewhat unsatisfactory. Here, we see exhibited interesting effects of multiplexing and the limitations of the state-of-the-art in network calculus to deal with this in an entirely satisfactory manner. Further generalizations of this approach are clearly warranted.
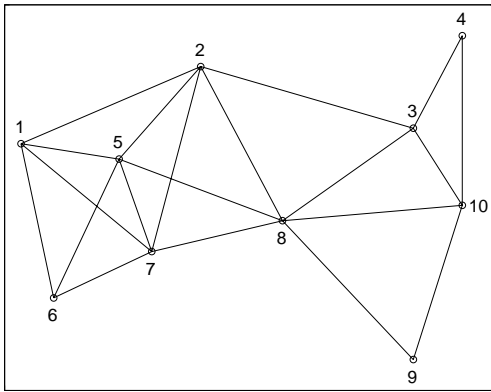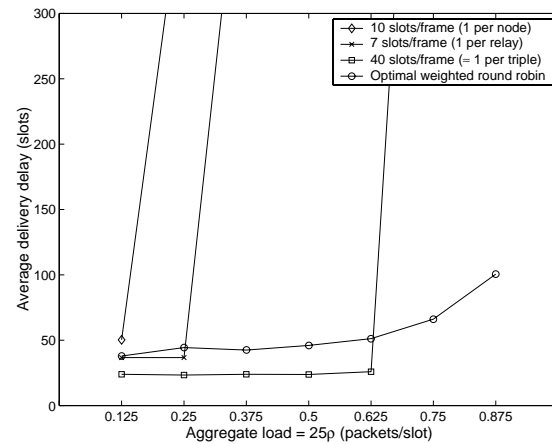

Figure 1. A 10-node network.

Figure 2. Performance results.

Development of Improvements to the UHF Advanced Digital Waveform

Sid Graser
D844, (619) 553–9691

Multi-h continuous phase modulation (CPM) is a modulation technique used over ultra-high-frequency (UHF) satellite communication (SATCOM) channels. It was implemented as a result of the Advanced Digital Waveform (ADW) program—the goal of which was to increase throughput on UHF SATCOM channels. The purpose of this ILIR project was to research techniques for further improving the power and bandwidth performance of multi-h CPM. Three methods for accomplishing this goal were explored. The first method was to increase the symbol alphabet size from four to eight symbols by encoding 3 bits per symbol instead of 2. The second method was to implement a partial response waveform, meaning that each symbol was shaped over multiple symbol periods. The third method was to increase the number of modulation indices. The first two areas of interest, 8-ary CPM and partial response CPM, showed promising results, and in some cases, improved both power and band-width efficiency. Three-h CPM did not improve performance and does not appear to be a promising avenue for further research. The work done in this project is applicable to improving the performance of UHF SATCOM channels by increasing data rates and also by lowering the power requirements of existing data rates.

BACKGROUND

The ultra-high-frequency (UHF) military satellite communications (MILSATCOM) band is divided into 42 5-kHz channels and 36 25-kHz channels. UHF has many desirable characteristics that are unavailable at different frequencies. Most notably, UHF terminals can use relatively small, less expensive terminals with non-directional antennas and can operate through weather and foliage. The downside of UHF is that the assets are very limited, and demand far exceeds available resources. In addition to the limited assets, the UHF satellites use a hard limiting, nonlinear transponder that prohibits the use of bandwidth-efficient modulations such as quadrature amplitude modulation (QAM).

The Advanced Digital Waveform (ADW) program produced the multi-h continuous phase modulation (CPM) waveform now specified in MIL-STD-188-181B. The ADW program greatly improved the throughput on UHF SATCOM but fell short of the original target data rates of 64 kbps and 12 kbps on 25- and 5-kHz channels, respectively. One goal of this project is to build on the accomplishments of ADW and develop the technology necessary to push the throughput on UHF channels to or beyond the target rates. Another goal is to improve the power efficiency of existing data rates so that disadvantaged users may have access to them. Therefore, it is desirable to improve both the power performance and the bandwidth efficiency of this waveform.

The probability of error, P_e, can be approximated as

$$P_e \cong Q(\sqrt{d_{\min}^2 (E_b / N_0)}) \tag{1}$$

for reasonably high signal-to-noise ratios. The quantity $d_{\min}^2$ is the minimum squared Euclidean distance of a waveform. The bit error rate (BER) is improved by lowering P_e. This can be done either

by increasing the power of a signal or by increasing the value of $d_{\min}^2$ associated with the particular waveform. By increasing $d_{\min}^2$, the BER is made better without increasing the power. This means the waveform has greater power efficiency. The bandwidth efficiency of a waveform is a ratio of a particular data rate to the amount of bandwidth required by that data rate, sometimes expressed as bps/Hz. The advantage of greater bandwidth efficiency is the ability to transmit higher data rates in the same amount of spectrum. Better power efficiency allows platforms with less gain to close links on higher data rates that would not otherwise be available.

CONTINUOUS PHASE MODULATION

The general CPM waveform is defined by

$$s(t,\alpha) = \sqrt{\frac{2E_s}{T_s}} \cos(2\pi f_0 t + \phi(t,\alpha)) , \qquad (2)$$

where E_s is the symbol energy, T_s is the symbol period, and f_0 is the carrier frequency. The $\phi(t,\alpha)$ term is the information carrying phase and is defined as

$$\phi(t,\alpha) = 2\pi \sum_i h_i \alpha_i q(t - iT_s) , \qquad (3)$$

where h_i is the modulation index, α_i is the data, and $q(t)$ is the phase response, which is the integral of the instantaneous frequency pulse, $g(t)$. The length, L, of $g(t)$ is the number of symbol periods over which each symbol is shaped. If $L <= 1$, the waveform is said to be full response. If $L > 1$, the waveform is partial response.

The MIL-STD-188-181B version of CPM uses two alternating values of h and is a 4-ary waveform, meaning there are four possible values of α. The instantaneous frequency pulse is rectangular and $L = 1$, thus it is a 1REC waveform.

RESEARCH AREAS

Three areas of potential improvement to this waveform have been explored. The first idea discussed is increasing the alphabet size of the waveform from 4 to 8. The next area of improvement is to move from a full response to a partial response system so that each symbol is shaped over multiple symbol periods. The third idea explored is to use more than two modulation indices.

In the 4-ary version of CPM, several sets of modulation indices are used and a general correlation exists between the size of the indices, the coding gain, and the spectral occupancy. Five sets of indices are specified in the standard. The lower modulation indices occupy less bandwidth but also have lower coding gains. The higher index sets have larger spectra at a given data rate but offer better BER. A classical power vs. bandwidth tradeoff exists here wherein bandwidth can be spent to buy power.

The 8-ary scheme has more trellis states so it is prudent to make the denominator 32 instead of 16 and determine which indices will provide the best coding gain. It turns out that the same correlation between modulation index size and coding gain is not present to the same degree using 8-ary CPM. Most of the higher minimum distance values result from index values less than 1/2. Using higher

indices than this consumes more bandwidth but does not buy the BER performance as it does in the 4-ary case.

The upside here is that good coding gain can be achieved at lower bandwidth than is possible using 4-ary. For example, if the indices $\{9/32, 12/32\}$ are used, 4.5 dB of gain can be achieved relative to MSK. The same gain can be had in 4-ary CPM using $\{12/16, 13/16\}$, but the 8-ary system uses slightly less bandwidth than the 4-ary system, and it provides higher throughput. The only cost is added complexity. Results from a simulated 8-ary system using these indices are not quite as good. 8-ary CPM underperforms the 4-ary system with the same theoretical gain by approximately 0.5 dB. Figure 1 compares the power and bandwidth properties of these waveforms.
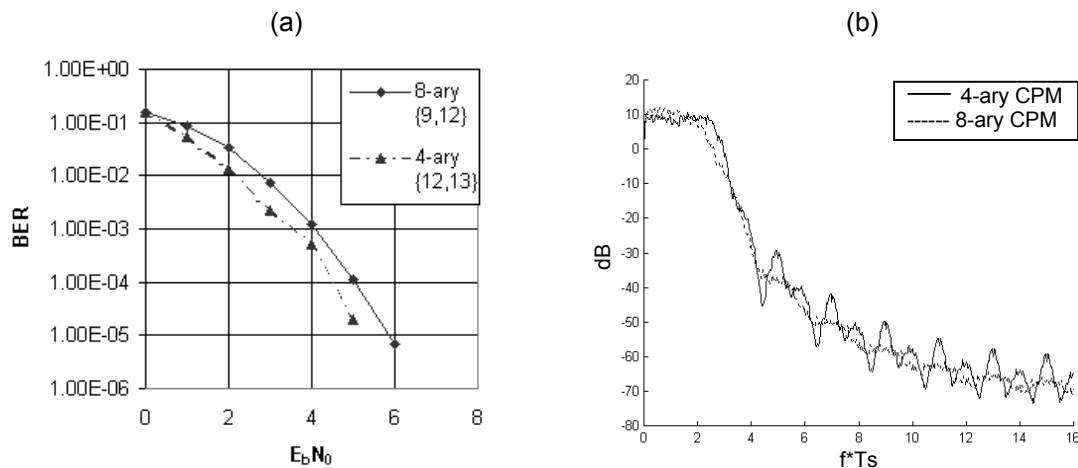
Figure 1. Comparison of 8-ary CPM using $\{9/32, 12/32\}$ and 4-ary CPM using $\{12/16, 13/16\}$.
1(a) shows the BER performances and 1(b) compares the power spectra at a fixed symbol rate.

The second topic of research is partial response CPM. Partial response means that each symbol is shaped over more than one symbol period. The technique chosen for this project is 3REC, meaning a rectangular instantaneous frequency pulse 3 symbols in length is used. The shape of the *nth* symbol being encoded depends not only on α_n, but also on α_{n-1} and α_{n-2}. This introduces more memory into the phase trellis, which translates into coding gain. It also greatly increases the decoder complexity.

An analysis of the minimum distances of various combinations of *h* values was performed on the 3REC CPM waveform. The phenomenon observed is that the lower indices of the partial response waveform perform poorly as compared to the full response version, but partial response exhibited higher theoretical gains at higher values of *h*. For example, the gain using the $\{4/16, 5/16\}$ index set is 1.5 dB lower for partial response than for full response, but at the high end, partial response outperforms full response by 1.3 dB using indices $\{12/16, 13/16\}$. These results are theoretical because a 2-*h* partial response decoder has not yet been simulated, but they are consistent with simulation results of simpler, single-*h* partial response schemes. Figure 2 shows a comparison between full response and partial response CPM.

(a)   (b)
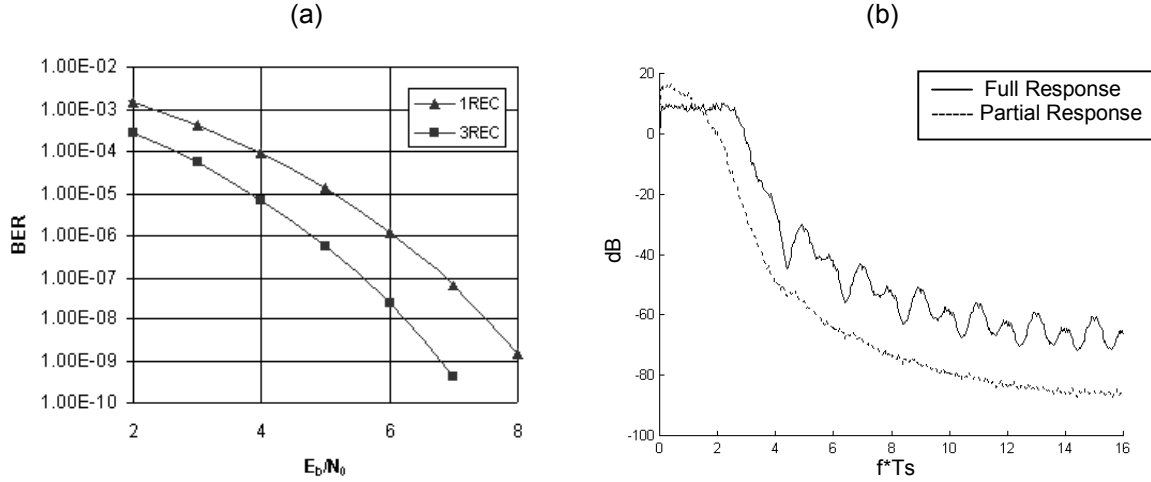
Figure 2. Comparison of (a) the theoretical P_e performance and (b) the power spectra of 3REC (Partial Response) and 1REC (Full Response) CPM using indices $\{12/16, 13/16\}$.

In terms of spectral efficiency, the bandwidth used by partial response is much less than a full response modulation with the same indices. If the two schemes are compared based on bandwidth requirements, the results are more impressive. The spectral occupancy of partial response using $\{12/16, 13/16\}$ is approximately the same as a full response scheme with indices $\{6/16, 7/16\}$. The gains relative to MSK of these schemes are 5.8 dB and 3.2 dB for the partial and full response schemes, respectively. Thus, switching to partial response provides a 2.6-dB gain. The caveat here is that it is difficult to know how much of this will be given back in implementation loss. There seems to be a tendency for a Viterbi decoder with a very large number of states to become "lost" in the trellis in the presence of a noisy signal. The other side of the implementation issue is that synchronization is more difficult with a partial response system. More work is needed in this area.

As has been discussed already, the MIL-STD CPM is a 2-h system, meaning two different modulation indices are used in an alternating fashion. This technique adds memory to the trellis and results in added coding gain when compared to an equivalent single-h system. Intuitively, it would seem that adding a third index and cycling them would increase the minimum distance of the system by spreading the trellis that much more.

An exhaustive analysis of the minimum distance of 3-h CPM was done that compares all combinations of indices. The results of this analysis indicate there is nothing to be gained by adding a third index. In almost every case, the third index hurts the performance of a 2-h scheme with similar spectral properties. The best that can really be done is to equal the performance of a 2-h system. Simulation of a 3-h system showed degradation in every case tried.

CONCLUSION

Three techniques for improving the power and bandwidth efficiency of UHF SATCOM have been studied in the course of this ILIR project. Of the three techniques, the most promising appears to be 8-ary CPM. Increasing the alphabet size of CPM allows better spectral efficiency, and the power efficiency is comparable to 4-ary in many cases. A big advantage to 8-ary CPM is that the complexity is

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not much greater than 4-ary CPM so it seems implementation would be relatively straightforward. Like 8-ary CPM, partial response CPM offers both power and bandwidth improvement. While also promising, partial response involves a greater degree of receiver complexity that 8-ary CPM. The only topic researched here that does not appear to hold promise is 3-*h* CPM.

The results of the research performed in this project highlight improvements that can be made in UHF SATCOM. There is great potential to improve the power and bandwidth characteristics of the MIL-STD-188-181B implementation of multi-*h* CPM. These results are relevant to the Navy in that they are applicable to further revision if MIL-STD-188-181B. In addition to military UHF SATCOM systems, results gained from this project are relevant to any communication system in which a constant envelope, bandwidth-efficient modulation scheme is desirable.

Applications of Stochastic Nonlinear Dynamics to Communications Arrays

Dr. Brian K. Meadows
D364, (619) 553–2823

This research employs two effects, nonlinearity and coupling, to develop dynamic nonlinear antennas. The project leverages recent advances in active antenna design and the theory of non-identical oscillators to generate beam steering and beam forming across the array of nonlinear oscillators. Merging nonlinear dynamics and radio frequency (RF) microelectronics creates an antenna design capable of providing a significant level of directivity in a small volume. Additionally, compact arrays (antennas with element spacing significantly smaller than a half-wavelength) are possible by directly coupling nonlinear elements. By "tuning" the spatial disorder between elements, dynamic interactions provide both beam forming and steering functions. An array of N-coupled nonlinear oscillators can produce any aperture taper (cosine-on-a-pedestal, Dolph-Chebychev, Taylor, and Villeneuve n-parameter schemes) while simultaneously steering the beam, thus eliminating the need for complex antenna algorithms. This design exploits the intrinsic-device physics to form the computational element based on continuous functions of time, space, voltage, current, and charge. Practically, an injected dc bias voltage controls the amplitude and natural frequency of the individual nonlinear oscillators. Advances in this research include analytic models that contain non-uniform amplitude profiles. Complementing the analytical and numerical studies of disorder in nonlinear arrays is a series of experiments on microelectronic coupled dynamic elements.

RESEARCH SUMMARY

The signal transmission from a Global Positioning System (GPS) satellite is composed of two spread-spectrum signals in quadrature. The transmitted signal level from the satellites provides approximately –160 dBw at the surface of the earth. Consequently, the signal is below the inherent thermal noise level. Such weak signals broadcast on known frequencies leave GPS navigation systems vulnerable to jamming. This vulnerability is well documented by the Naval Research Advisory Council. GPS countermeasures fall into two categories: a relatively small number of high power (approximately 10^4- to 10^5-Watt) jammers and a large number of low power (approximately 1- to 100-Watt) jammers distributed across the battlefield. Compounding the problem, highly mobile vehicles mounting GPS receivers preclude the use of strongly directive, large aperture antennas to mitigate the effects of jamming. Current antenna technology provides no ready solution to numerous low-power jammers. Subsequently, the objective is to obtain increased immunity to jamming and interference.

Nonlinear antenna technology relies on dynamic array processing at microwave and millimeter wave frequencies. Active antenna design employs diodes, transistors, or nonlinear circuits distributed over a plain surface that interact with the free-space beams at the plane of radiation collection. Combining free-space beams, rather than wave-guide modes or transmission-line voltages, results in lower insertion losses. The dynamic range of the array improves because the signal power (transmit or receive) is distributed across many devices. Active antennas differ fundamentally from passive antennas in two ways: the unit cells are nonlinear, and signal processing (dynamic interactions between cells) is

done via mutual coupling. In passive antenna arrays, which employ some multi-pole as the unit cell, prescribing the geometry of the array controls the radiation pattern. Due to superposition interacting, non-identical *linear* oscillators can only produce beats, not a single frequency, thus making it impossible to synchronize a linear array.

Active antennas are inherently nonlinear dynamic systems that can generate a number of unusual nonlinear phenomena. Over the last several years, an explosion of new analysis and control techniques for manipulating nonlinear dynamics has emerged. Active antenna design is ripe for the application of these new nonlinear techniques. Current array design practice strives to suppress any inter-element coupling while minimizing noise. However, the interplay between coupling and noise can be "tuned" to achieve optimal performance. This is done in a variety of ways in nonlinear devices including adjusting the coupling strength, changing the number elements in the array, dynamically controlling the device potential, introducing spatial disorder into the array, or optimizing the input noise. These nontraditional design approaches have already been experimentally verified in prototype antennas.

Generically, any active antenna design is an ensemble of coupled nonlinear devices. The dynamics of such arrays have been the subject of intense study in the last decade, with a particular focus on super-conducting oscillator arrays. Fortuitously, the equation that governs the motion of exotic supercon-ducting oscillators also describes the analog phase-locked loop (PLL), one of the building blocks in active antennas.

$$\ddot{\theta}_n + \gamma\dot{\theta}_n \cos\theta_n = -\omega_0^2 \sin\theta_n + A\sin(\omega_D t) + k(\theta_{n+1} - \theta_n) - k(\theta_n - \theta_{n-1}) \qquad (1)$$

Therefore, all the advances in understanding the dynamics of superconducting oscillator arrays may transfer to active antenna design. Figure 1 dramatically illustrates this point. This is a numerical simulation of a one-dimensional array of 17 analog PLLs. The PLLs are coupled via linear nearest neighbor with each element receiving a globally applied signal $A\sin(\omega_D t)$: The equation of motion is where θ_n is the phase error of the nth phase-locked loop in the chain; ω_{0_n} is the natural frequency of the nth PLL; and ω_D is the frequency of the global AC driving. Spatial disorder is introduced through variations in the natural frequency (ω_0) of each PLL.
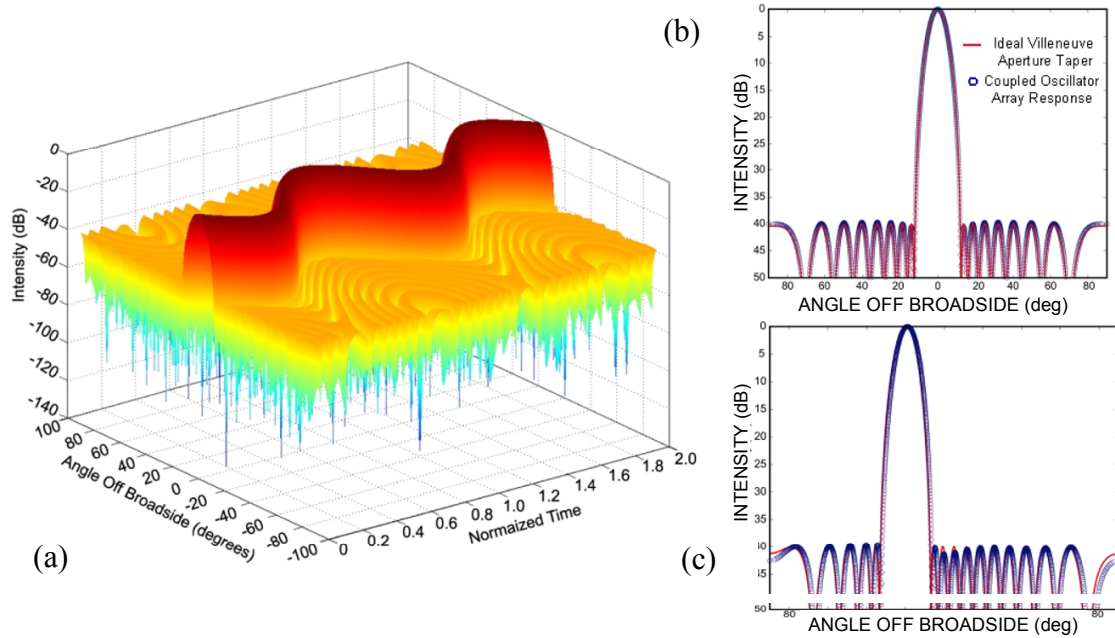
(b)

(a)

(c)

Figure 1a. A numerical simulation of a 1 by 17 phase-locked-loop array demonstrating a –40 dB sidelobe ratio. The array exploits amplitude dynamics to produce the appropriate weightings needed to reduce sidelobes, while the phase dynamics steer the beam sinusoidally. This is achieved through a separation of time scales and weak coupling. In particular, the uncoupled amplitude dynamics evolve on a time scale that is very fast relative to the phases. The amplitudes rapidly settle down to steady-state values yielding the desired weightings. These steady-state amplitude values will appear in the phase dynamics. Thus, the previous case of identical amplitudes (which led to the phase model description) was a special case of this more general approach incorporating non-identical amplitudes values. In other words, the amplitude ratios appearing in the phase dynamics will now be constant, non-unity values. System parameters can be identified that separately control the amplitudes and phases. Figure 1b shows the main beam pointing broadside illustrating that the amplitude dynamics can be used for tapering. Figure 1c illustrates the ability to simultaneously beam steer and taper the main beam. According to the phase model (developed previously under this ILIR project), the array can be modulated at frequency. For simplicity, a modulation frequency of 1 cycle per normalized time unit is shown. In both figures 1b–c, the solid line represents the ideal intensity pattern, and the circles signify the intensity pattern resulting from the coupled oscillator dynamics.

The experimental component includes the design and testing of microelectronic nonlinear arrays. Three robust nonlinear oscillator (van der Pol) designs are currently being fabricated in a complementary metal-oxide semiconductor (CMOS) process (see figure 2). The first chip contains two uncoupled oscillators but with accompanying circuitry to form discrete arrays with off-chip coupling. All parameters and variables are routed to pads for experimentation characterization. In addition, support circuitry and a minimum of additional components will allow for the construction of PLLs with the nonlinear oscillator at its core. Designs with fully coupled 1-D and 2-D arrays are also being fabricated. In these designs, global parameters are routed to pads, and the state of each element in the array can be measured using scanning circuitry. For the 1-D and 2-D arrays, the end and edge elements in the respective arrays can be frequency detuned for demonstrating beam-steering techniques.

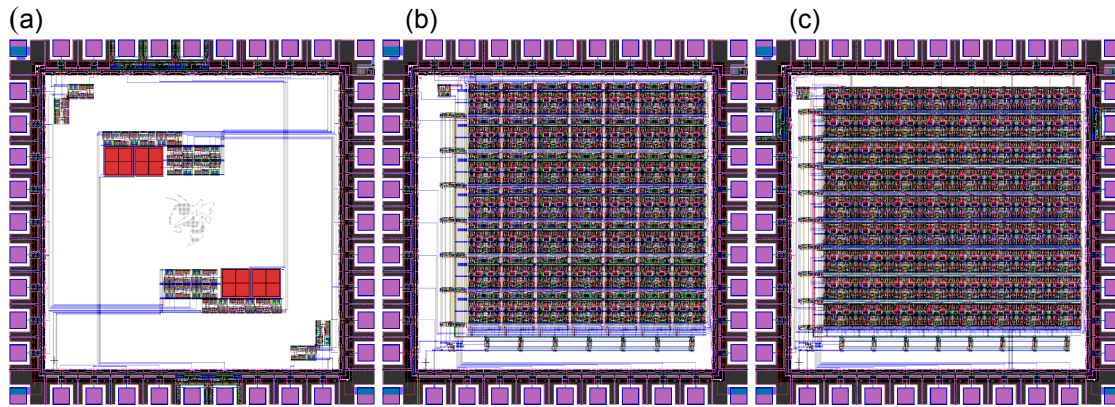(a)　　　　　　　(b)　　　　　　　(c)

Figure 2. Three robust van der Pol designs are currently being fabricated in a CMOS process.
Figure 2a shows a chip containing two uncoupled oscillators for characterization purposes.
Figure 2b shows a 1-D array of 49 locally coupled oscillators. The array has been folded for more
efficient use of chip space. Figure 2c shows a 2-D array of 72 locally coupled oscillators

Robust Waveform Design for Tactical Communications Channels

Dr. James R. Zeidler
D8505, (619) 553–1581

The objective of this research project was to develop the analytical tools required to evaluate the tradeoffs in data rate and security that are fundamental to the design of robust tactical communications networks. The critical parameters of the system are the waveform design, the transmitter and receiver antenna gain and directivity, the interference parameters, and the characteristics of the tactical communications channel. Our approach was to define the bit-error rates of several candidate waveforms as a function of the energy per bit, the number of bits per symbol, and other key signaling waveform parameters for candidate transmitter/receiver architectures. This analysis permits the evaluation of the tradeoffs in data rate and detectability of the transmitted waveforms. Nonlinear adaptive signal-processing techniques are being developed to mitigate the effects of hostile interference. This project addresses current naval needs for tactical littoral communications for the Marine Corps 2010 Communications Architecture for Operational Maneuvers from the Sea. Major results to date include the development of analytical tools that accurately predict the performance of prototype low-probability-of-detection (LPD) waveforms. A second major result was the development of nonlinear signal-processing techniques that maximize interference suppression with minimal distortion of the desired signal waveforms.

SUMMARY

The revolutionary advances in modern commercial telecommunications technology have provided significant promise for advances in the operational efficiency of military systems and have also improved quality of life for the sailors and Marines responsible for conducting operations around the world. However, commercial systems that provide real-time, worldwide access to multimedia information via the Internet often do not provide the security features required in tactical military operations. A critical requirement for rapid access to video and other information is the use of high-data-rate communications networks operating at rates exceeding 1 Mbps. Conversely, low probability of detection (LPD) systems often operate at data rates as low as 10 bps to minimize the probability of being detected by an adversary.

SSC San Diego is involved in numerous research and development efforts to provide high-speed communications capabilities to the Fleet. We also have a number of other efforts that are focused on providing communications security. One such effort is an ONR 6.2 effort to provide LPD communications for the Marine Corps. These LPD links are a requirement in the Marine Corps 2010 Communications Architecture for Operational Maneuvers from the Sea (OMFTS). A prototype system was developed to meet this requirement. In addition, a Cooperative Research and Development Agreement (CRADA) with Harris Corporation and Intersil is in progress to transfer the technology to the PRISM chipset (a commercial standard). Unfortunately, the realization of this transfer is impeded by the lack of a common baseline to meet the commercial requirements for high data rate while still maintaining a satisfactory level of LPD for military operations. It is the goal of this project to provide the analytical tools that will allow security and data-rate tradeoffs to be evaluated on a common

baseline and to define the waveforms and transmitter and receiver design parameters that will satisfy tactical military communications requirements without sacrificing data rate.

A number of references on the desirable waveforms that are under consideration as a standard for the High Data Rate IEEE 802.11 Extension are posted on the Intersil Web site http://www.intersil.com/design/prism/papers/

The waveforms that are under consideration include M-ary Orthogonal Signaling (MOS), Cyclic Code Shift Keying (CCSK), Pulse Position Modulation (PPM), Orthogonal Frequency Division Multiplexing (OFDM), Orthogonal Code Division Multiplexing (OCDM), M-ary Quadrature Amplitude Modulation (M-QAM), and Complementary Code Keying (CCK). The comparative performance of each of these is discussed in the above papers relative to the current Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) modulations that are the current IEEE 802.11 standards for the 1 Mbps and the 2 Mbps data modes. Additionally, the importance of antenna diversity in achieving reliable performance in fading channels is also documented in these papers.

The modulation format used in the LPD prototype developed at SSC San Diego for ONR 313 uses the CCSK modulation discussed above. CCSK is also used in the Joint Tactical Information Distribution System (JTIDS) and other military radio modems. A principle advantage of CCSK modulation is the implementation simplicity. One of our key results is that we proved that the probability of error performance for CCSK is equivalent to that of MOS. This result is significant because CCSK requires only the computation of the Fourier Transform of the received signal plus noise, F(r), followed by an inverse transform of the product of F(r) and the complex conjugate of the transmitted code, F(c). By contrast, implementation of MOS requires correlation of each of the M orthogonal functions with the received signal plus noise.

The differences in implementation thus become significant as M increases for MOS modulation. This is especially important for LPD applications because it is necessary to maintain low levels of transmit power in order to avoid detection by a hostile intercept receiver. This can be done by CCSK or MOS by increasing the length of the code to increase the coding gain. Under the ONR 6.2 program, field tests were performed with the prototype CCSK receiver in 1999. These tests verified that reliable communications at 25 bps could be achieved over a 48 mile line-of-sight channel between Mount Palomar and Building 40 on Point Loma using a transmit power level of 25 microwatts and 9 dbi directional antennas at the transmitter and receiver and a code length of 65,536 bits. The differences in implementation complexity between CCSK and MOS for codes of this length are significant.

Another significant result obtained this year was a proof that for the low values of signal-to-noise ratio (SNR) used in LPD applications, there is negligible difference in performance between a variety of methods that can be used to generate the modulation sequence. Comparisons of maximal length sequences (MLS), modified maximal length sequences (MMLS), and random sequences (RS) reveal that although MLS gives significantly improved performance at high SNR due to the improved peak to sidelobe ratio of the autocorrelation function, the results are insignificant at low SNR. This is significant for LPD applications because the set of maximal length sequences is relatively small, and the transmitter can potentially be intercepted by an exhaustive search over the limited number of MLS values. It was further shown that performance could be improved in some cases by using Gray codes to minimize the number of bit errors caused by timing or synchronization errors. A method to

recursively generate Gray codes was developed under this program and has been submitted for publication.

To quantify the vulnerability of a given waveform, it is necessary to define a performance metric that is standard for the range of waveforms considered. The baseline metric selected is the radiometer, and it was shown that CCSK and M-ary Frequency Shift Keying (MFSK) have equivalent vulnerability to a radiometer detector. It was further shown that MFSK is considerably more vulnerable to detection by a channelized receiver. The channelized receiver consists of a bank of bandpass filters with each filter followed by an energy detector.

Another major result in this effort was the development of nonlinear adaptive signal-processing techniques to mitigate hostile interference with minimal distortion of the communications signals. It has been proven that the nonlinear effects can be used to significantly improve performance.

The use of both space and time diversity is important both to high-data-rate and LPD systems. The publications on the Intersil Web site discuss the importance of antenna diversity to mitigate intersymbol interference (ISI) in high-data-rate modems. For LPD systems, the antenna diversity is important both for ISI and for minimizing the energy transmitted to hostile interceptors. This topic is being investigated in conjunction with UCSD. Methods to adapt the weights of the antenna to maximize the power delivered to the receiver have been developed and submitted for publication.

The channel models to be used in this effort were derived from the Naval Communications Channels (NCC) dataset. The NCC dataset contains over-the-air measurements of a High-Mobility Multipurpose Wheeled Vehicle (HMMWV) and a mobile Navy ship transmitting to a fixed shore site at 1 Mbps in the military ultra-high-frequency (UHF) band. This database was analyzed under this program to obtain tables giving the number of distinct paths and the delay, power level, Doppler shift, fade rate, and probability distribution of the fading on each path.

Work was initiated on the modification of CCSK to provide higher data rates and robustness in multipath. These are critical issues in the comparison with other modulation techniques under consideration for commercial standards. Multipath sensitivity is the key issue raised by Intersil relative to incorporation of CCSK into the commercial standards. In addition, comparisons to the commercial Code Division Multiple Access (CDMA) standards for cellular telephones and OFDM were also initiated. One of the properties of CCSK is that it is not efficient in its use of bandwidth since it requires that the bandwidth be doubled in order to increase the number of bits-per-symbol by one. This is a desirable property for LPD because it spreads the energy over frequency and maintains the same detectability margin. It is undesirable for commercial applications, however, because bandwidth is expensive. CDMA also requires more bandwidth to provide increased data rates. The goal of our CCSK/CDMA comparisons is to provide a thorough understanding of the tradeoffs in data rate and detectability between the two waveforms.

This effort was performed in collaboration with Dr. George Dillard, D73H; Dr. Jeff Allen, D363; Dr. Mike Reuter, D841; Chris Yerkes, D855; and students and faculty from the University of California at San Diego (UCSD). The UCSD effort has focused on CDMA, OFDM, and variants of CCSK, PPM, and other techniques for high-speed optical communications applications.

The published results of this effort include a journal publication, an invited conference presentation, and there are several publications in progress that will summarize the detection performance of

CCSK relative to MOS, the detectability metrics, and the Gray-code-generation technique. Additionally, we received invitations from three different publishers (Prentice-Hall, Artech, and Marcel-Dekker) to write a book on nonlinear adaptive signal-processing techniques.

High-Linearity Broadband Fiber-Optic Link Using Electro-Absorption Modulations with a Novel Dual-Wavelength Second-Harmonic Cancelation Scheme

Richard Nguyen
D859, (619) 553–5435

We demonstrated a broadband electro-absorption (EA) modulator link. The EA modulator has a third-order-distortion null bias point, good for suboctave analog transmission. To further suppress the modulator's second-order distortion for multi-octave transmission, we proposed a push-pull link architecture where complementary (inverted and noninverted) signals drive two EA modulators and the non-distorted transmitted signal is recovered through differential photo-detection. This demonstration was based on a prior patented technique (Navy Case 79,042).

BACKGROUND

Network and system architects must fully utilize available channel bandwidth in order to meet the need for increased information capacity to achieve the military's network-centric warfare vision. For intra-platform information exchange, the challenge is to maximize the analog/digital data flow through a single channel. The tremendous bandwidth capabilities of optical fibers make them the transmission medium of choice for next-generation military local area networks (LANs) and antenna networks. However, the linearity of the photonic links must be improved to take full advantage of the available bandwidth. Broadband analog or mixed-signal photonic links with improved linearity are required for shipboard antenna remoting, as well as radio frequency (RF) distribution and control of active phased-array antenna signals. Size, weight, and electro-magnetic interference (EMI) immunity offer additional advantages for the use of fiber-optic technology. Critical topside-design-engineering issues must be resolved. The photonic link envisioned for future shipboard (e.g., DD 21 and CVX) applications requires transmitting a combination of communication, radar, and electronic warfare signals over a single fiber. Due to the span of the signal spectrum, a broadband link is required. Present electro-absorption (EA) modulator links operating at a third harmonic null can linearly deliver signals over suboctave bandwidths with low third-order harmonic distortions, but this use for multi-octave transmission is limited by the modulator's second-order harmonic distortion.

Recently, SSC San Diego's Dr. C. K. Sun and Dr. Steve Pappert invented a dual-wavelength link transmission scheme to suppress second harmonic distortion generated by the modulator. This dual-wavelength transmission scheme is particularly beneficial for suppressing the second harmonic distortion generated by the EA modulator, thus enabling the possibility of using the EA modulator for broadband transmission with improved linearity. To demonstrate this novel concept, efficient EA modulators working at two slightly different wavelengths are required. Low optical insertion loss and high RF efficiency are essential modulator requirements for this high-linearity approach to be successful.

APPROACH

The proposed EA modulator development for improved performance included semiconductor material and device structure design modifications, and improvement in the fabrication process. High-quality

epi-materials with different bandgap energies were acquired from the University of California at San Diego (UCSD) and tailored for low optical propagation losses at selected laser wavelengths. The EA modulator had to have a high level of material growth controlability and good electrical properties. A large optical cavity waveguide design was investigated to lower the fiber-to-fiber optical coupling loss. Fabrication improvement had to reduce waveguide scattering loss due to surface roughness associated with the wet chemical etching process. The novel dual-wavelength transmission link used two modulators, operating at two slightly different wavelengths. The RF signals applied to the two modulators were 180° out of phase. The optical signals were combined through a wavelength-division-multiplexing (WDM) coupler, transmitted through a single fiber, de-multiplexed through a WDM coupler, then detected by a balanced photo-detector, which combined two RF signals with one 180° phase-inverted signal. This transmission scheme eliminated even-order harmonic distortions in the link due to push–pull operation, similar to a class AB amplifier. The combination of achieving efficient modulators and using dual-wavelength link transmission enabled us to demonstrate a broadband, high-linearity fiber-optic link.

RESULTS

The FY 00 goal was to design and fabricate an EA modulator suitable for push–pull operation. Navy and UCSD jointly designed and fabricated EA modulators operating in the 1550-nm-wavelength range, based on our 1310-nm EA modulator technique. The switching of wavelength allowed us to use standardized laser wavelengths at 1550 nm for WDM combining. We designed and fabricated a preliminary 1550 modulator with its transfer curve (figure 1). The device had a diode capacitance of 200 fF and a 3-dB bandwidth of 8 GHz (figure 2). The optical insertion loss of this device was 18 dB, higher than the desired insertion loss of < 14 dB. UCSD performed an extensive simulation study to improve the fiber-to-modulator coupling loss. Figure 3 shows the simulated mode profile of the waveguide structure. The elliptical mode profile caused mismatch between the waveguide and the input fiber with circular mode profile. To minimize this mismatch, UCSD designed a large optical cavity (LOC) waveguide structure (figure 4). With the LOC structure, the simulated result showed that the coupling optical insertion loss can be improved by 3 dB. We believe that the combination of LOC structure and short (~200-µm) EA modulator should yield an optical insertion loss less than 14 dB.
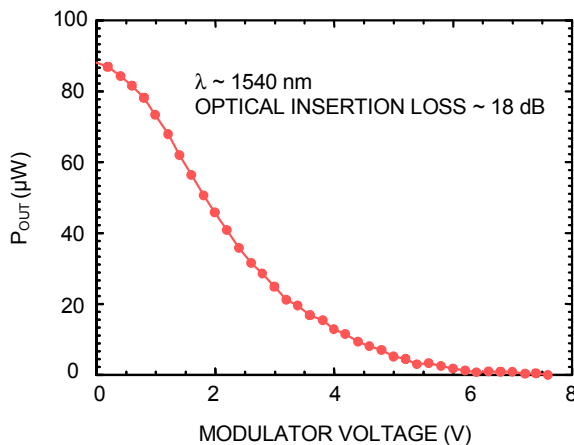
Figure 1. The transfer curve of a 1540-nM EA modulator.
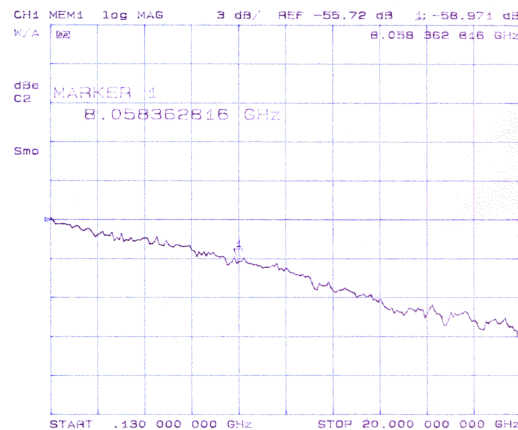
Figure 2. The frequency response of the modulator.

CONTOUR MAP OF TRANSVERSE INDEX PROFILE AT Z=0

Q(1.46)

CONTOUR MAP OF TRANSVERSE INDEX PROFILE AT Z=0

Q(1.24)
Q(1.46)
Q(1.24)

COMPUTED TRANSVERSE MODE PROFILE
(m=0,n_{efi}=3.394588)

COMPUTED TRANSVERSE MODE PROFILE
(m=0,n_{eff}=3.314248)
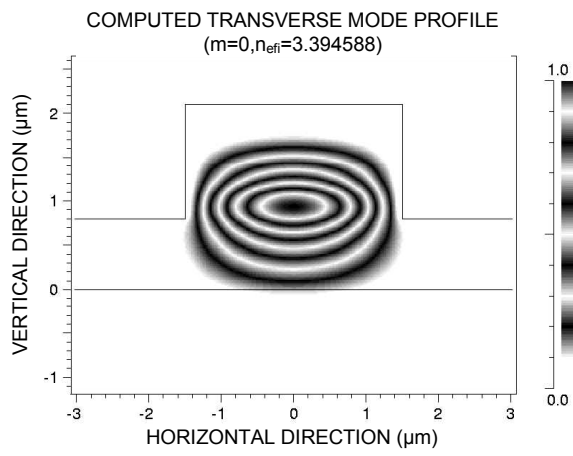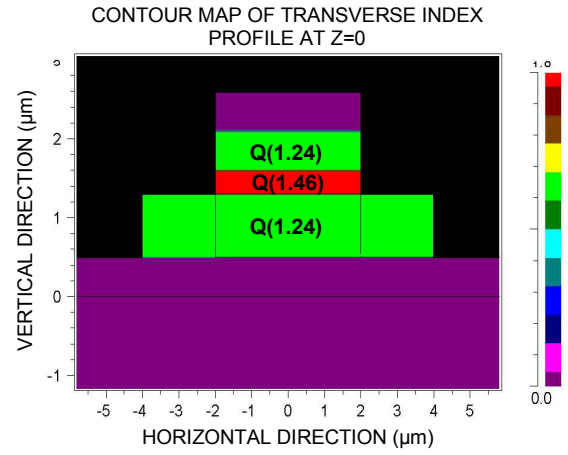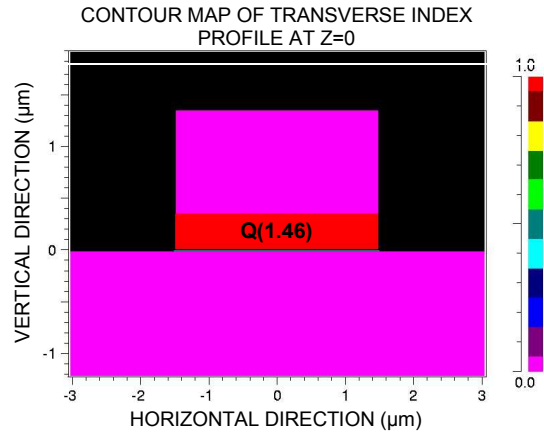
Figure 3. The device structure and corresponding mode profile.

Figure 4. The LOC device structure and the corresponding mode profile.

Intelligence, Surveillance, and Reconnaissance

Sonar Waveform Design

James Alsup
D711, (619) 553–2498

The objective of the Sonar Waveform Design project is to improve current Doppler-sensitive waveform capability through the derivation and implementation of a new power-efficient, Doppler-and-range resolving waveform. Our approach has been two-fold: first, design the "Triplet-Pair" waveform to improve efficiency in the use of the sonar projector, and second, design the "Hermite Function Space" waveform and the associated "Constrained, Regularized Deconvolution" processing method to achieve unparalleled Doppler sensitivity for use in littoral antisubmarine warfare (ASW). We succeeded in both objectives, having submitted a patent application for the first, and having written papers for both topics that have been presented at scientific meetings and seminars. We believe the technology developed in this project will be used to support active sonar used in naval surveillance and tactical systems designed for use in littoral waters, where good Doppler-sensitive waveforms are becoming more important in the requirement to reach down into the very-low Doppler regime where enemy submarines can otherwise hide undetected.

BACKGROUND

This project is of great interest to SSC San Diego and the Navy because of the need to make sonars work better in littoral waters, where active sonar is required to find quiet targets. Doppler is the key to reducing false alarms, and concurrent range resolution provides improvement in both false alarm rate and tracking accuracy.

Current waveforms used for the littoral typically include a mix of frequency modulations (FMs) and continuous waves (CWs), with a few super frequency modulations (SFMs), Newhalls, or Geometric Combs also. These latter three attempt to provide simultaneous range and Doppler resolution but are not optimum either because of increased ambiguity in the range-Doppler plane or because of inefficient use of available power from the acoustic projector.

OBJECTIVES

The Sonar Waveform Design project seeks to improve current Doppler-sensitive waveform capability through (1) the derivation and implementation of a power-efficient waveform based on the geometric comb and (2) the derivation and implementation of a new class of waveforms with high resolution in both range and Doppler based on the Hermite functions.

APPROACH

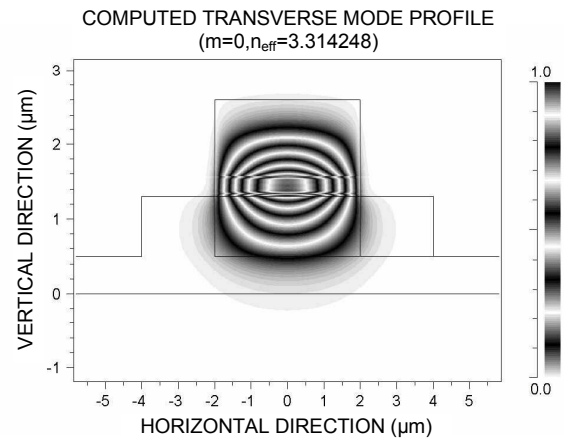1. Design a Triplet-Pair waveform. This new waveform is intended to retain the resolution in Doppler and range associated with the recent Geometric Comb waveform [1], while improving its power efficiency, thus permitting the waveform to function well in both ambient-noise-limited environments and reverberation-limited environments. The design serves as a stepping-stone to further waveform development in (2).

2. Design a Hermite Function Space (HFS) waveform/processor. This new waveform/processor combination is intended to show even better Doppler resolution than all the waveforms discussed above, and to provide excellent range resolution and power efficiency as well, making it perhaps the ultimate Doppler-sensitive waveform for use in littoral waters.

RESULTS

1. A new Doppler-sensitive waveform, the Triplet-Pair waveform, has a very high power effciency of –3 dB. The Triplet-Pair waveform is a type of comb waveform, similar to the Geometric Comb [1], in which three adjacent tines of the comb are amplitude-weighted in such a way that their combination results in a low-rate modulation of the center tine. A second triplet is similarly weighted, such that its (same) low-rate modulation is delayed by a half-cycle of the modulation. When the two triplets are then added together, the peaks of one and the valleys of the other are in alignment, such that the overall envelope of the waveform is approximately flat, thus resulting in high power efficiency. When a second pair of triplets is formed, the progression of frequencies across the 12 tines looks quasi-geometric, and accounts for the slight improvement in delay (range) resolution that also characterizes the geometric comb.

2. A new waveform/processor, the Hermite Function Space (HFS), has perhaps the best reverberation-suppression characteristics of any Doppler-sensitive waveform seen in naval sonar practice. The HFS waveform itself is composed of a group of Hermite functions, each of which is used to weight the amplitude of a tine of a "comb" spectrum. Each tine represents a single-frequency pulse of specified duration, so that the weighted pulse has the same shape as the associated Hermite function. The sum of these tines constitutes the final waveform, and represents a "space" of Hermite functions having joint properties superior to those of the individual components. The processing method recommended for this waveform is known as the "constrained, regularized deconvolution" (CRD) method, a technique originally developed for deblurring images in the Hubble Space Telescope. The combination of using the CRD processing method with the HFS waveform design allows the sonar engineer to achieve unequaled resolution in Doppler (figure 1), superior range resolution, and relatively high efficiency in sonar-projector power usage.
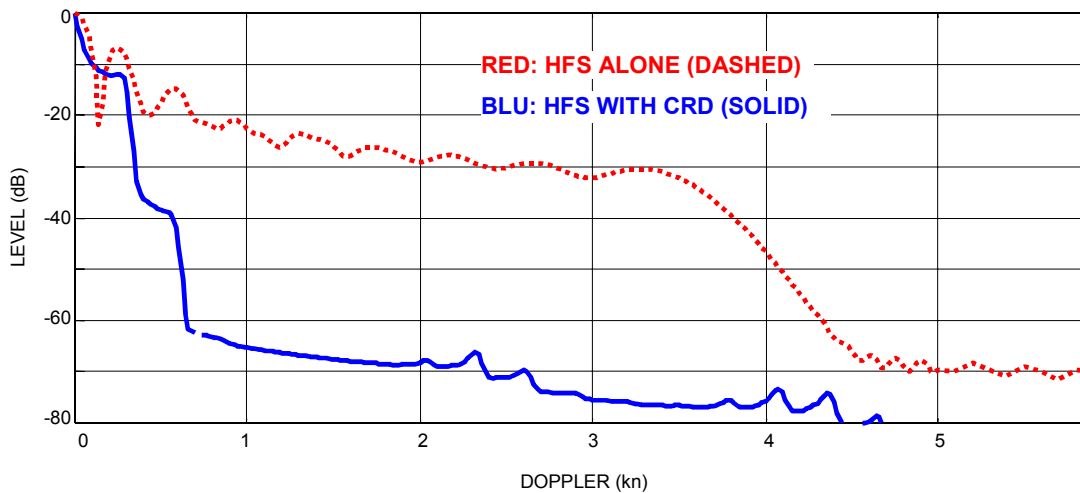
Figure 1. HFS Q-functions, T = 10, fc = 500 Hz, N = 8. Graph shows amount of reverberation that can be suppressed by these waveforms as a function of target Doppler.

IMPACT/APPLICATIONS

The technology developed in this project is intended to support active sonar systems used in naval surveillance and tactical applications, including the use of deployed sources and receivers in multi-static configurations. In particular, the technology is designed to be used in littoral waters, where one objective may be to detect third-world diesel/electric submarines whose passive signatures have become virtually undetectable, and whose active-sonar echoes may be characterized by both low target strength and low Doppler content. When Doppler is not taken into account, an active sonar system operating in shallow water is likely to become swamped with false alarms from which true target echoes cannot be distinguished. Thus, good Doppler-sensitive waveforms are becoming more important, and even better waveforms of this type will permit the sonar system to reach down into the very low Doppler regime otherwise exploitable by this type of target.

ACKNOWLEDGMENT

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Environmental Adaptive Matched-Field Tracking

Dr. Homer Bucker
D857, (619) 553–3093

This project demonstrates the automatic detection of a submarine in a littoral environment by using an inexpensive deployable line array of hydrophones. We found a target track that had the highest value of matched-field correlation for a 3- to 5-minute period of time. The depth of the track was the discriminate used to separate submarines from surface ships. In the first year of this program, a six-element, vertical-line array was used to detect targets in a shallow-water area close to San Diego. Work in the second year focused on developing algorithms to be used with a six-element, bottom-line array in the Adriatic Sea, as part of the Remote Deployable Systems (RDS)-3 experiment. Good results were obtained from a preliminary test in local waters.

SUMMARY

The hostile diesel-electric submarine is a serious and increasing threat to U.S. Navy/Marine operations in littoral waters. This threat requires that we develop detection systems with improved performance. Also, reduction in Navy personnel requires systems with little or no operator input. The matched-field tracking algorithm satisfies both mandates by using all available acoustic data to generate estimates of target depth, speed, and direction. The designation of a target as submerged solves 98% of the classification problem.

Three techniques were introduced in FY 00 to ensure the matched-field tracking algorithm will operate in real time. These techniques were range-demodulation of the calculated sound field, image warping of the normal mode depth functions, and use of selected elements of the covariance matrix. The following discussion details analysis of data from three sea tests.

Although the kernel of matched-field tracking is the common matched filter, practical application of the algorithm requires searching for tracks in a five-dimensional space. These coordinates are the x and y values of A and B, and the target depth. This processing can be done in real time by storing the predicted range-demodulated hydrophone values in a large number of tables. The track correlations are quickly calculated by using table lookup. In the first data set, hydrophone data from six sensors of a vertical line array (VLA) near San Clemente Island were used. Results were published in the December 1999 issue of the *Journal of the Accoustical Society of America* (JASA) [1].

The second data set tracked the U.S. research submarine, *Dolphin* (AGSS 55), in Dabob Bay. Data were collected on a short bottom array. We selected a set of frequency bins with the best (S+N)/N ratios, after constant false alarm rate (CFAR) normalization, for the analysis. To obtain the required range-demodulated tables at the specific frequencies, we used image warping of the normal modes and were careful to locate the zero-crossings and maximum response of the modes. A paper on this work will be submitted to the U.S. Navy *Journal of Underwater Acoustics*.

The third data set, collected during the Remote Deployable Systems (RDS)-3 experiment in the Adriatic Sea from 3 to 16 October, is currently being analyzed. Matched-field tracking was implemented in a node of a shallow-water barrier. To reduce the number of points in the initial search grid, only selected elements of the covariance matrix were used (i.e., those hydrophone pairs with separations <=150 m). Results of this analysis was reported in a paper by Mark Stevenson and Homer Bucker at the December 2000 meeting of the Acoustical Society of America.

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Coherent Mid-Infrared Optical Parametric Oscillator

Dr. Frank E. Hanson
D853, (619) 553–2094

This project's objective was to develop and characterize a coherent mid-infrared (mid-IR) source near 3.6 μm and demonstrate the potential for coherent laser radar applications, including micro-Doppler measurements of target vibration signatures. A mid-IR laser radar is expected to have superior performance in low-altitude naval environments compared to near- and far-IR systems. In this project, an optical parametric oscillator (OPO) based on periodically poled lithium niobate (PPLN) and a frequency-stable, 1-μm pump source was built and demonstrated. The OPO cavity resonated both the pump and signal waves and had a pump threshold of ~0.5 W. This approach avoided the thermal instabilities of the signal and idler resonant cavity. However, the large intracavity 1-μm intensity led to significant second-harmonic generation at 0.532 μm and associated photorefractive loss in the PPLN crystal. This resulted in transient operation of the OPO. A more robust OPO source was built under contract and delivered late in the program. A heterodyne laser radar experiment using this source is proceeding. The experiment is designed to measure small Doppler shifts from calibrated moving targets in the laboratory.

SUMMARY

Laser radar techniques to measure small Doppler shifts from hard targets have been successfully demonstrated using laser sources at several wavelengths including 1 μm, 1.5 μm, 2 μm, and 9 μm. It has been shown that skin vibration spectra due to the target power plant can be obtained and used to identify unknown targets. In many cases, there are no other alternative methods to identify targets at long range. However, in the majority of littoral environments where the Navy operates, atmospheric scattering, turbulence, and humidity can degrade coherent laser radar performance significantly. Scattering and turbulence have a more adverse effect at shorter wavelengths, whereas transmission at the 9- to 10-μm CO_2 laser wavelengths is severely limited by humidity. Performance modeling based on an extensive weather database has shown that coherent laser radar in the mid-infrared (mid-IR) near 3.8 μm would generally perform better than at shorter or longer wavelengths in expected Navy scenarios. The advantage is especially significant for paths in the lower atmosphere from a ship-based platform. Power levels of a few Watts and coherence times of a few 100 μs would probably be required for such a laser radar to be useful in fielded military systems. Up to now, sufficiently coherent sources have not been demonstrated in the laboratory at this wavelength.

The goal of this work has been to demonstrate the feasibility of coherent heterodyne laser radar at 3.5 to 3.8 μm and to demonstrate a practical source at this wavelength with sufficient power for naval applications. An optical parametric oscillator (OPO) source offers wide frequency tunability and the use of the recently developed nonlinear material, periodically poled lithium neobate (PPLN), offers a much larger nonlinear gain than conventional bulk nonlinear materials. Two approaches for achieving a low threshold and frequency-stable mid-IR source were pursued. A double resonant OPO where both the signal and idler waves were resonated was demonstrated. However, the low intrinsic absorption of PPLN at the idler wavelength led to unstable operation. A second approach was tried in which

the pump and signal wavelengths were resonated. The OPO did operate with a pump threshold of ~0.5 W. However, this approach resulted in significant levels of second harmonic generation at 532 nm due to the high intracavity pump intensity. Some green generation is unavoidable, and therefore, the PPLN must be kept at an elevated temperature to anneal the induced photorefractive damage and resulting optical loss. Our PPLN oven was, unfortunately, not capable of operating at the high temperature required, and the OPO output was unstable. The pump-signal resonant approach is technically feasible and has been demonstrated by others. A robust, high-temperature OPO source was built under contract and delivered late in the program.

A laboratory experiment to demonstrate heterodyne laser radar using the commercial source was designed and is currently in progress. The experiment will measure Doppler shifts from a calibrated moving target and make quantitative comparisons of measured and predicted carrier-to-noise ratio (CNR). In addition, several potential long-path experiments from Point Loma (San Diego) have been studied. Such important outdoor experiments would allow performance correlation with weather conditions and should be feasible with some moderate investment in telescope optics.

Adaptive Stochastic Mixture Processing for Hyperspectral Imaging

Dr. David W. J. Stein, D743, (619) 553–2533
Dr. Scott G. Beaven, D855, (619) 553–4186
Dr. Stephen E. Stewart, D745, (619) 553–2546

This work focused on two aspects of processing hyperspectral imagery (HSI). By reducing the dimension of the data while preserving the signal-to-noise ratio (SNR), anomaly detection can be improved by up to 5 or more dB, depending on the dimensionality reduction achieved, the SNR, and the probability of false alarm (PFA). We developed a class of transforms that preserve SNR for signals contained within a subspace, which we call the signal-subspace preservation (SSP) algorithm, and a whitened vector quantization (WVQ) transform such that the relative or absolute loss in SNR from applying the transform is less than or equal to a selected upper bound. Data analysis shows that the WVQ and SSP techniques can have much better signal-preserving characteristics for a given reduction in dimension than either the vector quantization (VQ) or principal component (PC) transforms. We have also extended multivariate classification techniques to compositional data. The response from each pixel is modeled as a linear combination of samples such that each sample emanates from a multivariate normal distribution. The maximum likelihood equation is solved to estimate the abundance and contribution of each class at each pixel. Preliminary results show that if the classes have sufficient variability, then detection algorithms derived from the stochastic unmixing model have superior performance to those derived from the deterministic mixture model.

BACKGROUND

The principal component (PC) [1, 2], maximum noise fraction (MNF) [1, 3], or vector quantization (VQ) [4, 5] transforms are commonly used as an initial step in the analysis of hyperspectral data. These transforms have been used to determine a subspace for further analysis, e.g., end-member determination [3, 4, 5] or for lossy data compression [2, 5]. These methods are not generally optimal for detection purposes. The projection of the observations onto the first k PC planes provides a transform to dimension k that minimizes mean-square error [6] among transforms to dimension k. The MNF transform [1] is based on the model $x = s + n$, where s and n are the scene and noise radiance components, respectively. By solving a generalized eigenvector problem, it provides an ordered basis for the observation space such that the transformed noise components and the trans-formed scene-plus-noise components are uncorrelated, and the ratio of scene-plus-noise variance to noise variance is decreasing. Compression [3] is achieved by selecting k and projecting onto the first k MNF vectors. Vector quantization [4, 5] projects the data onto a subspace such that the angle between the projected vector and the original is less than a given tolerance. The effect of VQ on mean-square error and on classification have been evaluated empirically [5], and the effects of PC and VQ combined with wavelet compression on target detectability (using an anomaly detector) and on material identification have also been studied empirically [2].

The availability of spectral imaging sensors and the advanced methods for processing spectral sensor data have made it possible to accomplish passive remote material identification (ID) over large areas. However, except for pixels filled entirely with a single material under ideal lighting conditions with

low sensor and environmental clutter noise, material ID is difficult and prone to error. Linear unmixing (LUM) techniques [3] have been developed to deal with deterministic mixtures of materials in a single pixel. Multivariate classification techniques (e.g., the stochastic expectation maximization [SEM] [7] algorithm) model pure pixels with random variation. However, no processing algorithm, as yet, deals with both conditions simultaneously. Part of the objective of this project is to develop such an algorithm that we call stochastic mixture modeling (SMM).

Often the purpose of processing image data is to detect the presence and position of a particular target material or anomalous material in the scene. The LUM algorithms and SEM typically do not incorporate target detection as part of the algorithm. LUM algorithms find a basis set of spectra (end-members) and determine the fractional abundance of each end-member in each scene pixel. SEM determines a set of spectral classes contained in a scene and assigns each scene pixel to a class. Target detection in spectral-image data has often been accomplished with spectral-anomaly detectors such as the Reed–Xioali (RX) algorithm or with spectral matched filters, but these detectors often fail because they are based on assumptions of local Gaussian statistics or pure deterministic spectra in the image pixels. This project will also integrate appropriate formal detection methods within the SMM framework.

OBJECTIVES

The focus of this research was to evaluate the effect of principal component and vector quantization transforms on target detectability from hyperspectral imagery and develop transforms that preserve or have controlled losses in SNR. Another objective was to develop an algorithm to accomplish spectral mixture analysis that takes into account the natural variation in material spectra due to sensor noise, illumination conditions, and other factors, and to couple this approach with a formal detection algorithm to detect anomalous materials or predefined spectral signatures.

APPROACH

For additive signals in Gaussian noise, assuming known background mean and covariance (as illustrated in figure 1), the performance of the matched filter is determined by the SNR, and SNR and the number of degrees of freedom, which is the number of independent dimensions of the data, determine the performance of quadratic detectors. Thus, if the dimension of the data can be reduced while the SNR is preserved, the performance of the anomaly detector can be enhanced. For example, if the dimension is reduced from 100 to 2 bands, the probability of detection of an 18-dB target rises from approximately 0.2 to approximately 1.0.

To determine the effect of widely applied transforms on detectability in hyperspectral imagery, we develop a formula for the loss in SNR from the application of a linear transform. We express the loss for the transforms of interest in these terms. We then develop (1) transforms that have no loss in SNR for signals contained within a known subspace and (2) transforms such that either the relative or absolute loss in SNR is bounded. These transforms were then applied to hyperspectral imagery.
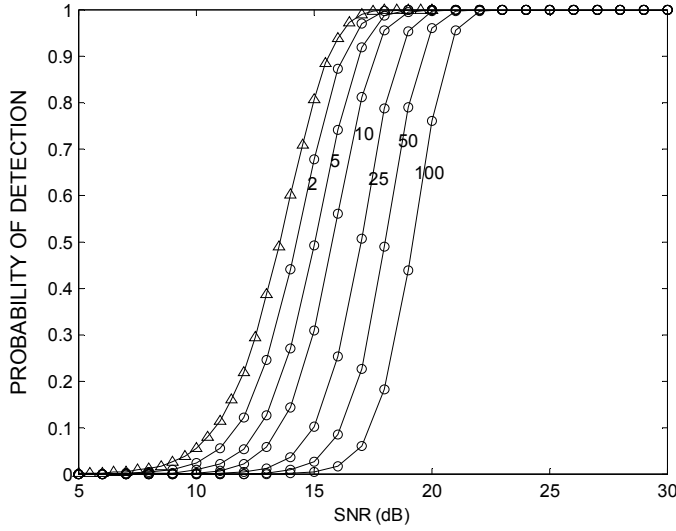
*Figure 1. Probability of detection of the matched filter ($\triangle$)
and the quadratic anomaly detector ($\bigcirc$) in Gaussian noise
as a function of SNR such that DOF = 2, 5, 10, 25, 50, and
100 and PFA = 10^{-6}.*

To develop a method for incorporating randomness in the analysis of mixed pixels, we use a multi-variate normal model for each class and one of several probability distributions for the fill-fraction of each class. Given these distributions, we optimize the likelihood function for the abundances and the class contributions. An anomaly detector is immediately available by thresholding the likelihood function. We construct a likelihood ratio detector by unmixing the data with and without the hypo-thetical targets and computing the ratio of the corresponding likelihood functions. Class statistics are initialized by using a deterministic unmixing approach and iteratively updated by computing the class sample mean and covariance from the maximum likelihood class contributions that are determined using the stochastic unmixing algorithm.

RESULTS

We developed an expression for the loss in SNR due to preprocessing multidimensional data with a linear transformation. This result was applied to the MNF, PC, and VQ transforms that are com-monly applied in hyperspectral analysis. We showed that these transforms can significantly degrade target contrast. For example, figure 2 is the result of applying the RX detector to ocean hyperspectral data that has been reduced with a vector quantization algorithm from 48 dimensions to 48, 36, 20, 12, 9, and 7 dimensions, respectively. One sees, for example, that the 7-dimensional vector quantization transform has essentially destroyed the target contrast. We defined a whitened-vector-quantization transform (WVQ) that is similar to VQ but based on an SNR criterion rather than an angle criterion [8]. This algorithm was applied to the same data, and as seen in figure 3, target contrast is preserved at the level of the 2-dimensional transform. Furthermore, as predicted in figure 1, the performance of the RX algorithm is enhanced by dimensionality reduction that preserves SNR.
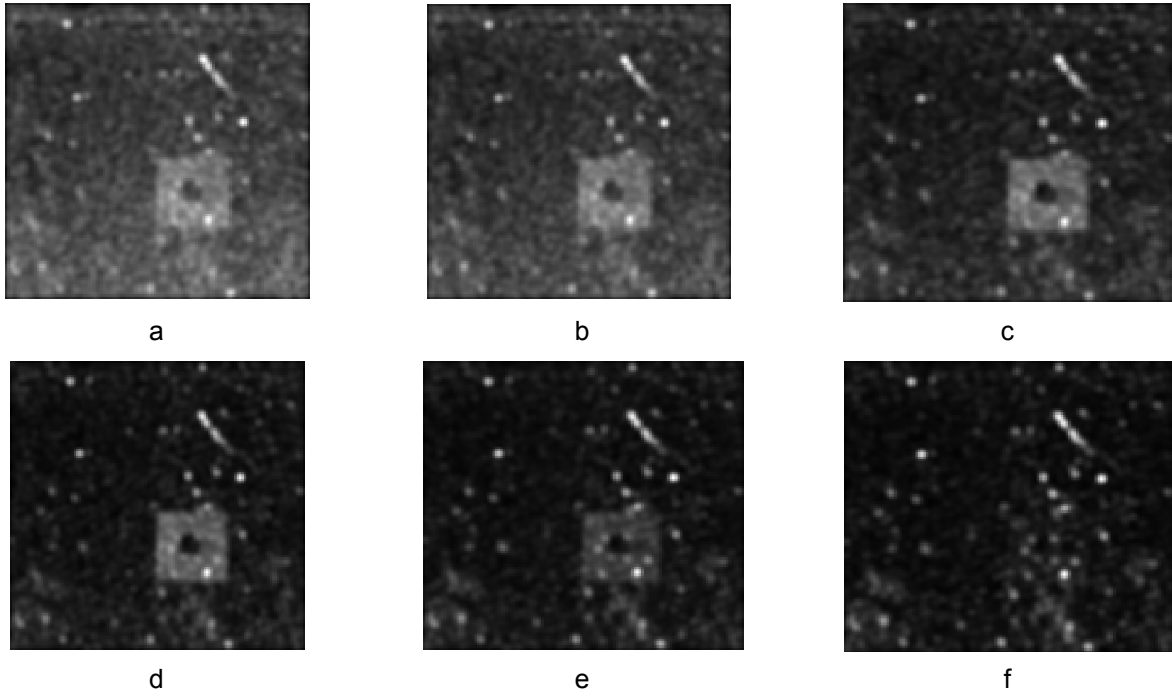
Figure 2. The RX algorithm applied to VQ transformed 48-band hyperspectral imagery transformed to 48, 36, 20, 12, 9, and 7 dimensions in (a) through (f), respectively.
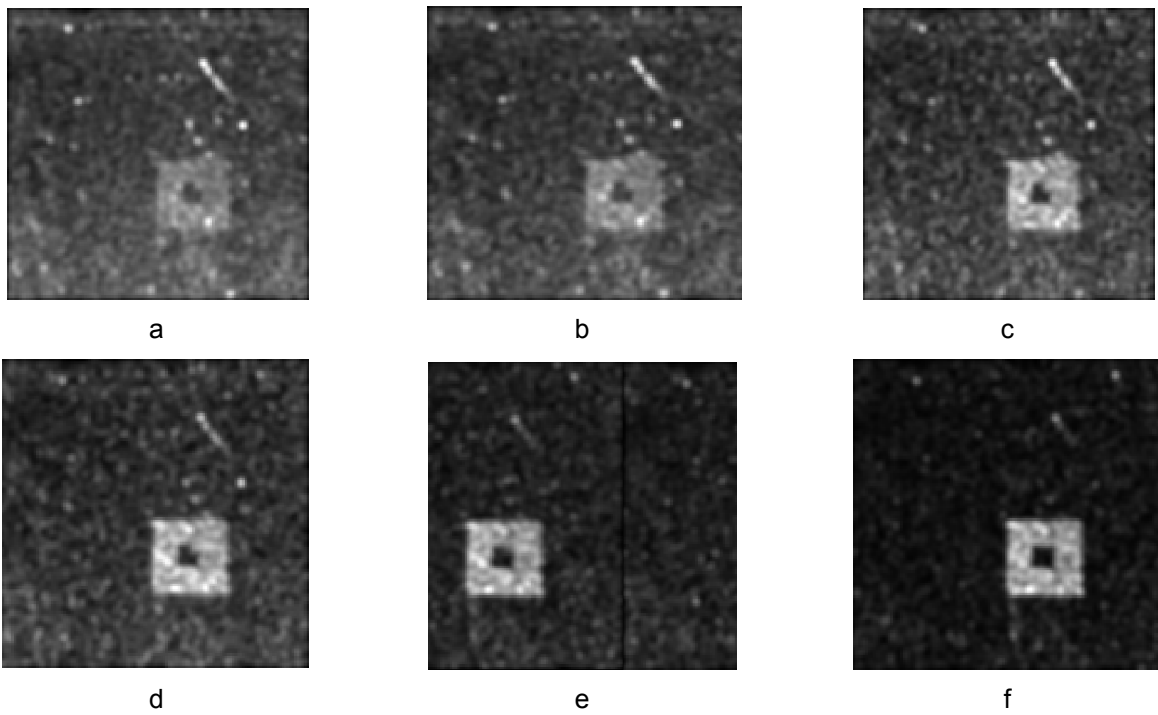
Figure 3. The RX algorithm applied to WVQ transformed 48-band hyperspectral imagery transformed to 48, 36, 24, 8, 4, and 2 dimensions in (a) through (f), respectively.

We have developed the foundations for stochastic mixture models and stochastic unmixing. We have developed and implemented several methods of initializing the statistical estimates and optimizing the likelihood function. We are currently evaluating and refining the techniques. Work is ongoing to evaluate the estimators and unmixing routines. Preliminary results suggest that stochastic unmixing will lead to significantly improved target detection algorithms. For example, figures 4 and 5 compare the results of deterministic and stochastic unmixing, respectively, on simulated hyperspectral data. The data were generated by combining random samples from two normally distributed classes. At five widely separated pixels, the combined vectors were replaced with the sample of one of five different target signatures. The class statistics and target signatures were obtained from hyperspectral imagery taken over land. For this problem, the target signature is not among the end-members, and therefore, target detection proceeds by examining the residual after unmixing rather than the end-member fraction planes. Figure 4 plots the magnitude of the residual after unmixing the data using the class means as end-members. Figure 5 plots minus the log-likelihood of the observation given the maximum likelihood estimates of the class contributions and abundance obtained from stochastic unmixing. At the proper threshold of the likelihood function, four of the five targets are found without any false alarms when using stochastic unmixing (figure 5), whereas none of the targets are found without false alarms when using deterministic unmixing (figure 4). The efficacy of the stochastic unmixing approach will be investigated further during the coming fiscal year.
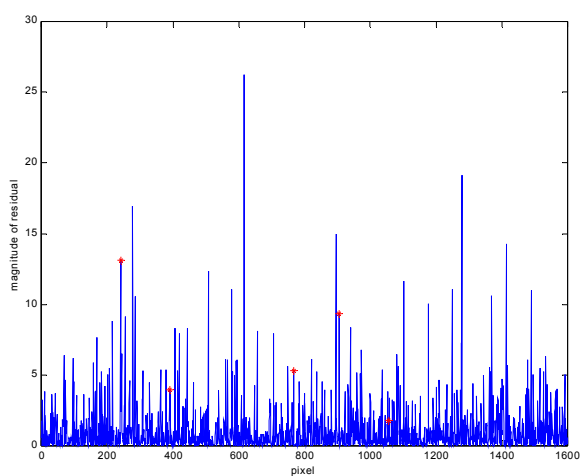
Figure 4. Magnitude of the residual of simulated hyperspectral imagery after deterministic unmixing. Asterisk indicates target pixels.
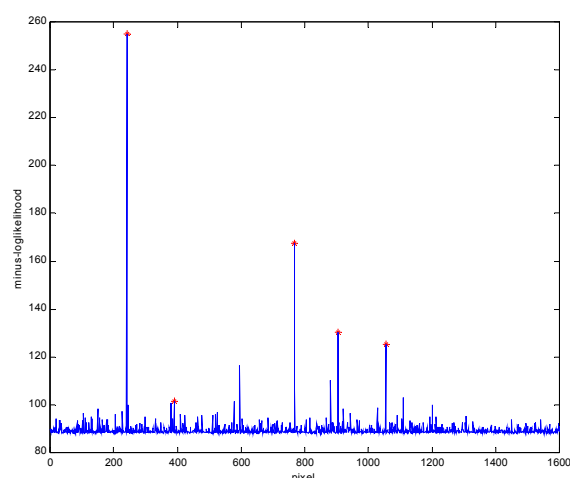
Figure 5. Magnitude of the residual of simulated hyperspectral imagery after stochastic unmixing. Asterisk indicates target pixels.

NAVY RELEVANCE

Understanding the effect of pre-processing transforms on signal detectability is crucial to the successful application of hyperspectral technology. For example, the Naval EarthMap Observer (NEMO) satellite proposes to use a form of vector quantization [5] onboard prior to downloading the imagery. As demonstrated here, this may lead to a reduced ability to detect targets of interest. Furthermore, hyperspectral imagery is often transformed prior to end-member selection and linear unmixing. Such transforms may result in the end-member selection process producing a model of the background

such that targets may be more readily discerned in the residual, rather than in the endmember fraction planes. The transforms developed during the course of this project demonstrate improved SNR preservation vis-a-vis the PC or VQ transforms. Application of these techniques to radar and communications are currently being explored. Stochastic unmixing provides a method of modeling the variability of spectra within a mixed pixel framework, and a coherent formulation for both anomaly and likelihood ratio detection methods. These ideas could lead to significant improvement in target detection from hyperspectral imagery.

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Super-Composite Slotted-Cylinder Projector

Dr. Po-Yun Tang
D746, (619) 553–1938

This ILIR project explored and demonstrated whether the bending-extension (b-e) coupling effect of graphite/epoxy two-layered cross-ply laminate can substantially improve (reduce fundamental natural frequencies of) low-frequency, wall-driven composite projectors (such as the slotted-cylinder projector). The super-composite beam and split-cylinder experiments were conducted to achieve this objective as well as to provide experimental data to confirm theoretical predictions (made with previously derived analytical solutions) on b-e coupled composite beams with simple supports. A total of 21 flat and curved shapes of bare-beam and actuator-beam specimens, respectively, were fabricated and tested in free and forced vibrations under the simply-supported and/or free-free boundary conditions. Excellent experimental data on fundamental frequencies were obtained for all seven bare-beam specimens and five fully-bonded actuator-beam specimens. These data remarkably confirmed the theoretical predictions for simply-supported flat bare-beam and actuator-beam specimens, with less than 2.0% differences between the data and the predictions. These data also clearly demonstrated the bending-extension coupling effect, yielding the following substantial reduction in fundamental frequency: (a) 38.9%, 38.5%, and 38.3%, respectively, for simply-supported flat, free-free supported flat, and free-free supported curved bare-beam specimens; and (b) 19.2% for free-free supported curved actuator-beam specimens with an actuator/beam thickness ratio of 1.0.

SUMMARY

This project is an outgrowth of our research on developing super-performance, low-frequency, wall-driven, composite projectors, which use piezoelectric translator (PZT) or high-energy density active materials as actuators and fiber-reinforced composites with bending-extension (b-e) coupling properties as radiator materials. The project's technical focus is on exploring and demonstrating the b-e coupling effects for potentials of substantial (up to 20 to 40%) improvements in either resonant frequency or size reductions of the low-frequency, wall-driven composite projectors currently used in mobile and deployed ocean surveillance systems. Obviously, the size-reduction improvement is particularly desirable for the Navy because of the reduction in platform limitations, drag limitations towed sources, and costs of making and operating these projectors.

As is well known, the basic acoustic-radiation mechanism for all wall-driven projectors is the conversion of the extensionally actuated deformation of the actuator into the bending motion of the radiator, thus radiating acoustic waves through water for detecting targets such as submarines. In light of this, it seems beneficial to study the use of a radiator material with inherent b-e coupling properties, such as the N-layered regular (equal thickness layers) antisymmetric cross-ply laminate. For such a b-e coupled composite, the largest coupling occurs at $N = 2$ (two-layered cross-ply laminate), whereas the coupling vanishes as N (even number) approaches infinity (homogenized or near-symmetric cross-ply laminate).

In FY 94 (ONR-sponsored) and FY 95 (SSC San Diego-sponsored) exploratory theoretical studies [1, 2, 3] were conducted on the (in-air) free vibration and induced strain actuation (forced vibration) of b-e coupled composite beams bonded to one side or both sides with actuator(s) and split cylindrical shells bonded to their concave side with an actuator. These studies favorably concluded that substantial bending deformation increases and fundamental frequency reductions of the simply-supported composite beams and split cylinders can be achieved with graphite/epoxy, Kevlar 49/epoxy, and s-glass/epoxy two-layered cross-ply laminates, as compared with near-symmetric cross-ply laminates.

In FY 96, experimental investigations were initiated to confirm theoretical predictions on b-e coupled composite beams with simple supports. SSC San Diego planned a program of controlled experiments on both bare-beams and actuator-beams made of graphite/epoxy cross-ply laminates. The program included the static bending and free vibration tests of simply-supported graphite/epoxy two-layered and near-symmetric cross-ply laminated (bare) beams and (bare) split cylinders, and the induced strain actuation and free vibration tests of the above-mentioned beams and split cylinders bonded with a PZT actuator to one side of the beams and the concave side of the cylinders, respectively. San Diego State University (SDSU) was contracted to fabricate specified test specimens (Principal Investigator: Dr. James Burns) and to conduct planned static and dynamic tests (Principal Investigator: Dr. Chen Liang) to obtain data required for comparisons with theoretical predictions. Unfortunately, the death of Dr. Liang caused a major setback to the project. Dr. Burns attempted to complete the remaining contracted work at no additional cost to the government.

In FY 97 and FY 98, both SSC San Diego and SDSU struggled to make progress under the constraints of no funding. SDSU fabricated most of the specimens and started a limited number of rudimentary free vibration tests on beam specimens. SDSU found that (a) testing fixtures for simple supports required substantial modifications; (b) these test specimens were easier to test in the free-free boundary conditions than the planned simply-supported boundary conditions; and (c) these specimens yielded encouraging results only in the free-free boundary conditions. Since the free-free boundary conditions were exactly those for an operating slotted cylinder projector, SSC San Diego decided to include the free-free boundary conditions in the experimental program.

However, both SSC San Diego and SDSU realized that funding was the key to real progress. Thus, in FY 99 and FY 00, SSC San Diego granted SDSU additional funding to complete the remainder of the super composite beam and split cylinder experiments. The results obtained so far have been documented in a preliminary report [4] and are highlighted below.

These experiments had two main objectives: (1) explore and demonstrate whether the bending-extension (b-e) coupling effect of graphite/epoxy two-layered cross-ply laminate has the potential to substantially improve (e.g., substantially reduce the fundamental [natural] frequencies of) low-frequency, wall-driven composite projectors, such as the slotted cylinder projector; (2) provide experimental data to confirm theoretical predictions (with analytical solutions previously developed by SSC San Diego [1,2,3]) on b-e coupled composite beams with simple supports.

Flat and curved (i.e., 180° split circular cylindrical shell) shapes of bare-beam and actuator-beam specimens were planned for fabrication, using graphite/epoxy two-layered and near-symmetric cross-ply laminates. The basic flat laminated beam had nominal dimensions of 10" (length) x 1.65" (width) x 0.2" (thickness), while the basic curved laminated beam had an inner radius of 3.18", width of

1.65", and thickness of 0.2". The bare-beams were basic laminated beams without any actuator bonded to them. The flat actuator-beams were fabricated from the basic flat laminated beams with a PZT (PZT-4) actuator fully bonded (at room temperature) to one side of the 0° layer of the beams in two actuator/beam thickness ratios of 0.5 and 1.0. The curved actuator-beams were fabricated from the basic curved laminated beams with a PZT (PZT-4) actuator fully bonded (at room temperature) to the concave side of the 0° layer of the curved beams in two actuator/beam thickness ratios of 0.5 and 1.0. It was planned to have a total of 12 groups of specimens. With two duplicates for each group, the total number of planned specimens was 24. The contractor, SDSU, was able to fabricate 21 specimens, consisting of 7 (4 flat and 3 curved) bare-beams and 14 (7 flat and 7 curved) actuator-beams.

Free vibration tests on the fabricated bare-beams and forced vibration tests on the actuator-beams were jointly conducted by SSC San Diego and SDSU in 1999 in the High Voltage and Materials Testing Laboratory of SSC San Diego. Free vibrations were generated by five different methods of mechanical excitation: fingernail flick, soft and hard hits with a large rubber mallet, and soft and hard hits with a small modal hammer. Forced vibration was generated by electrical excitation of the PZT actuator bonded to the specimen. Moreover, all flat specimens were tested in both the simply-supported and the free-free boundary conditions, whereas all curved specimens were tested only in the free-free boundary conditions, due to the setup of the current testing fixtures for simple supports. Furthermore, the free and forced vibration testing results on the fundamental frequency of the specimens were measured by the Fast Fourier Transform (FFT) measuring group and the Swept Sine measuring group, respectively, of the SRS Model SR780 network signal analyzer.

Excellent data were obtained from all bare-beam specimens: (a) The fundamental frequency data are essentially independent of the above-mentioned five different mechanical excitation methods, and their specimen-to-specimen variations are negligibly small. (b) With simple supports, the average experimental data on the fundamental frequency and the relative fundamental frequency obtained from the flat specimens are within 1.45% of the theoretical predictions made by SSC San Diego with previously derived analytical solutions. (c) With free-free supports, the average experimental data on the relative fundamental frequency obtained from the flat and curved specimens are nearly identical; also, they are practically the same (with a maximum difference of 0.98%) as data obtained from the simply-supported flat specimens. This and the result stated in item (b) above seem to suggest that the theoretical predictions made by the available analytical solutions or the experimental data for the relative fundamental frequency of simply-supported flat bare-beams could be used to estimate the relative fundamental frequency of the free-free supported pertaining flat and curved bare-beams. (d) All experimental data clearly demonstrate that the b-e coupling effect of graphite/epoxy two-layered cross-ply laminate substantially reduces the fundamental frequency of near-symmetric composite specimens. More specifically, the reduction is 38.9% for simply-supported flat specimens, 38.5% for free-free supported flat specimens, and 38.3% for free-free supported curved specimens.

Unlike bare-beam specimens, only a few (5 out of 14) actuator-beam specimens yielded reportable data, whereas the rest might have to be refabricated and retested due to suspected poor bonding between the actuator and the composite of these specimens. Fortunately, from the five fully-bonded specimens, excellent data were obtained: (a) With simple supports, the experimental data on the fundamental frequency of two flat two-layered cross-ply laminated actuator-beams with different actuator/beam thickness ratios are within 1.80% of the theoretical predictions made by SSC San Diego with previously derived analytical solutions. (b) With free-free supports, the experimental data on the

relative fundamental frequency of two curved actuator-beam specimens with an actuator/beam thickness ratio of 1.0 clearly demonstrate that the b-e coupling effect of graphite/epoxy two-layered cross-ply laminate substantially reduces (by 19.2%) the fundamental frequency of near-symmetric specimens); also, the relative fundamental frequency data are within 2.28% of the prediction with the available analytical solutions for simply-supported flat actuator-beams with an actuator/beam thickness ratio of 1.0. This and the result stated in item (a) seem to suggest that the theoretical predictions made by the available analytical solutions or the experimental data for the relative fundamental frequency of simply-supported flat actuator-beams could be used to estimate the relative fundamental frequency of the free-free supported pertaining curved actuator-beams.

Based on the above summarized results of all bare-beam and five fully-bonded actuator-beam specimens, the following conclusions can be drawn: (a) The bending-extension (b-e) coupling effect of graphite/epoxy two-layered cross-ply laminate has the potential to substantially reduce (by 20 to 40%) the fundamental frequencies of low-frequency, wall-driven composite projectors, such as the slotted cylinder projector. (b) The experimental data have confirmed the theoretical predictions (made with analytical solutions previously derived by SSC San Diego) for b-e coupled composite beams with simple supports.

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Navigation and Applied Sciences

Sensitivity of Marine Mammals to Low-Frequency Acoustic Pressure and Particle Motion

Dr. Samuel H. Ridgway, D3503, (619) 553–1374
Dr. James J. Finneran, D351, (619) 553–1343

*The relative contributions of acoustic pressure and particle velocity to the low-frequency, underwater hearing abilities of the bottlenose dolphin (***Tursiops truncatus***), white whale (***Delphinapterus leucas***), and California sea lion (***Zalophus californianus***) were investigated by measuring hearing thresholds while manipulating the relationship between the acoustic pressure and particle velocity. The work was accomplished by (1) varying the distance within the nearfield of a single underwater sound projector and (2) using two underwater sound projectors and an active sound control system. Animal subjects were trained to station on an underwater biteplate and participate in hearing tests in which they produced audible responses to tone + noise trials and remained silent during noise only trials. Stimulus intensity was adjusted (while maintaining the pressure/velocity relationship) by using a modified staircase procedure. Custom software was developed to calibrate the acoustic system, conduct hearing tests, and analyze the resulting data. Masked-hearing thresholds were measured at 100 and 300 Hz by using a single projector at 1, 2, and 4 m and at 300 Hz by using the active control system. Preliminary data suggest a lack of particle-motion sensitivity in the dolphin and white whale.*

BACKGROUND

Concern that man-made noise in the ocean may compromise the hearing or affect the behavior of marine mammals has given rise to legal actions that have resulted in costly delays and expensive modification to Navy projects. In addition, the discovery of dead whales often brings into question possible involvement of human activities, especially naval activities, in the mortality event. At present, there is a critical lack of knowledge on which to base decisions concerning the effects of underwater sound on marine species, including whales, dolphins, and sea lions. There is also a near total lack of information concerning the possible effects of acoustic particle motion (i.e., displacement, velocity, or acceleration) on marine mammals.

At present, there are only limited data on the sensitivity of marine mammals to acoustic particle motion. Johnson [1, 2] measured similar hearing thresholds for a dolphin using two different source locations and concluded that the thresholds were not affected by nearfield particle motion. Turl [3] observed a decrease in sound pressure thresholds in *Tursiops* between 50 and 150 Hz and suspected that the animals may have been detecting particle velocity. Kastak and Schusterman [4] measured aerial and underwater hearing thresholds in several species of pinnipeds and suspected a sensory modality shift (sound detection to vibration detection) below 100 Hz.

OBJECTIVES

The objective of this study was to determine the relative contributions of acoustic pressure and particle motion to the low-frequency, underwater hearing abilities of the bottlenose dolphin (*Tursiops truncatus*), white whale (*Delphinapterus leucas*), and California sea lion (*Zalophus californianus*).

Data were obtained by measuring masked underwater hearing thresholds while manipulating the relationship between acoustic pressure and particle velocity. This effort is the first systematic study of the relative contributions to marine mammal audition made by acoustic pressure and particle motion.

APPROACH

A behavioral response paradigm was used to measure underwater hearing thresholds while manipulating the pressure/velocity (p/v) relationship by (1) varying the distance within the nearfield of a single source and (2) using an active sound control system. Animals available for this study were trained to produce audible responses to hearing test tones. The source levels were varied, while maintaining the proper p/v relationship, in a staircase procedure until the threshold was determined. The approach is similar to previous research conducted on teleost (bony) fish in which the sound field's p/v ratio was varied to determine whether the subject was sensitive to acoustic particle motion or acoustic pressure.

RESULTS

A bottlenose dolphin and white whale were trained to station on an underwater biteplate and participate in hearing tests. Individual hearing test trials consisted of a 3.5-s noise burst alone (N) or a noise burst along with a 1-s tone (S+N). Subjects were trained to produce an audible response to S+N trials and to remain silent for N trials. Stimulus intensity was adjusted (while maintaining the *p/v* ratio) using a modified staircase procedure. Hearing thresholds were based on 10 response/no-response reversal points. Custom software was developed to calibrate the acoustic system, conduct hearing tests, and analyze the resulting data. A custom system was also developed to generate band-limited white noise whose frequency spectrum is compensated for projector response and acoustic standing waves [5].

Data were collected in two separate experiments. In experiment I, thresholds were measured at 100 and 300 Hz at distances of 1, 2, and 4 m from a single underwater sound projector; over these distances, the specific acoustic impedance ratio varied from approximately –10 to 0 dB at 100 Hz and –3 to 0 dB at 300 Hz. At 100 and 300 Hz, both the white whale and the dolphin displayed no significant differences between their pressure thresholds at the three distances. These data suggest that the subjects were either insensitive to acoustic particle motion or were ignoring it.

Experiment II featured two sound sources and an active sound control system. A pattern search algorithm [6] was used to adjust the amplitude and phase of the secondary source (see [7]) to achieve six distinct acoustic conditions at the test subject: (1) low p/v, (2) primary source only, (3) farfield (p/v in-phase), (4) high p/v, (5) secondary source only, and (6) nearfield (p/v out of phase). Experimentally mapped acoustic fields at each condition agreed reasonably well with a simple model consisting of two monopole sources in an unbounded medium. For this experiment, each subject was trained to station on a biteplate rotated 90º, so that its median plane was horizontal and both ears were within a vertical plane. This orientation placed both ears at the same distance from the sound-sources and within the region of optimal sound field control. Masked thresholds were measured using the same procedure as in experiment. I. Preliminary results again suggest that the dolphin and white whale were insensitive to particle motion cues.

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Electronic Properties of Cubic Boron Nitride

Dr. Wayne C. McGinnis
D364, (619) 553–5610

The conductivity and carrier mobility of semiconducting cubic boron nitride (c-BN) have been characterized using newly developed methods for making ohmic contact to this material. The approach for making contact to c-BN is to deposit metal electrodes which, when thermally reacted with BN, form conducting carbide and boride compounds in intimate contact with both the c-BN and the remaining unreacted metal. In-situ measurements during furnace annealing show continuous improvement of the current-voltage characteristic and lowering of contact resistance as the anneal temperature is increased to about 650 ºC. The contacts degrade at higher temperatures. Transport measurements using this contact method on c-BN thin films provided by the University of Michigan give room temperature conductivity (p-type) and Hall mobility values of 166 •$^{-1}$ cm^{-1} and 200 cm^2 V^{-1} s^{-1}, respectively. High-voltage/high-current switches and other solid-state devices made with this technology can be used for switching, control, and power conversion circuits on Navy ships, aircraft, and other vehicles. In addition, a solid-state neutron detector based on these materials would enable highly sensitive, portable sensors of nuclear materials.

SUMMARY

The cubic phase of boron nitride (c-BN) can be made semiconducting by doping with n- or p-type dopants. Because of its wide energy bandgap (about 6.4 eV), c-BN is a promising material for high-temperature/high-power electronic devices. Other wide-bandgap semiconductors, such as diamond, silicon carbide (SiC), and gallium nitride (GaN), have received much research attention for these applications. These materials, however, lack some of the important features of BN, such as stability at high temperatures in oxidizing atmospheres, or the ability to dope as either n- or p-type. One of the major impediments to using BN as a high-temperature semiconductor has been the lack of a good way to make ohmic electrical contact to the material. Because this problem has only recently been overcome [1], there have been essentially no measurements of the important electronic properties of c-BN, such as carrier mobility, and no reliable basis for comparing BN to other semiconducting electronic materials. Addressing this lack of basic materials information, contacting techniques, and film transport property measurements has been the focus of this project.

Navy, DoD, and civilian applications of c-BN as a high-temperature semiconductor include high-voltage/high-current switches and other solid-state devices for use in switching, control, and power conversion circuits in ships, aircraft, and other vehicles. In addition, a solid-state neutron detector taking advantage of c-BN as a semiconductor with a high cross section for thermal neutrons would enable highly sensitive, portable sensors of nuclear materials.

The BN contacting method employed in this research is similar to that developed here at SSC San Diego to make such contacts to semiconducting diamond [2]. In that case, a metal such as molybdenum (Mo) is deposited onto the diamond substrate or film and then furnace-annealed, reacting with carbon to form conducting molybdenum carbide. The semiconducting-diamond/carbide combination forms an ohmic contact. For the case of boron nitride, titanium metal is used to coat

semiconducting c-BN, and the sample is then heated in an inert-atmosphere. Ti reacts with BN to form titanium nitride and titanium diboride, both of which are conducting.

Cubic boron nitride films, deposited on n-type silicon, were provided by Dr. Roy Clarke of the University of Michigan. Layers of titanium, tungsten (diffusion barrier), and silver (wire bonding layer) were sequentially deposited through a lithographically defined photoresist stencil onto the c-BN surface in a single pump-down of an ultra-high-vacuum ion beam sputtering system. Two types of contact patterns were used: one for linear transmission line model (TLM) analysis of contact resistance [3], and another for four-point conductivity and Hall effect measurements [4]. After lift-off of the photoresist, gold wire ball bonds were made to the silver surface of the metal contacts. The bonds were fortified with a coating of silver paint.

To determine the proper reaction temperature for the BN-Ti interface, the current-voltage (I-V) characteristics and contact resistance of the TLM sample were measured *in-situ* in flowing argon in a tube furnace as a function of temperature. The results of these measurements are summarized in figures 1 and 2. The contact resistance continually decreased as the temperature increased to about 650 ºC, and sharply increased at higher temperatures. Degradation of the contacts is also indicated by the non-linear I-V curves measured after this temperature had been reached.
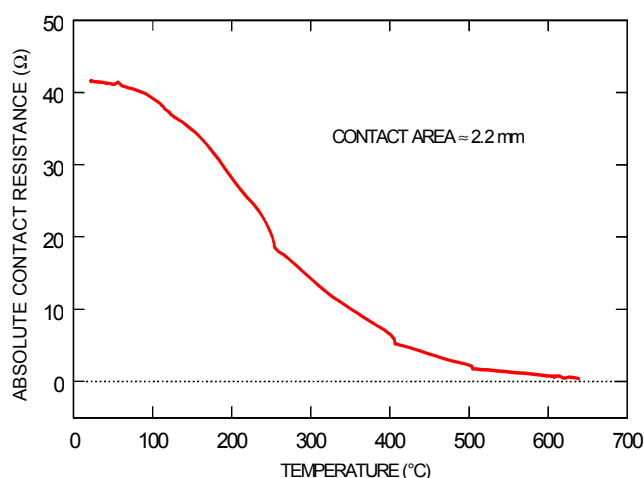
Figure 1. Absolute contact resistance of silver/tungsten/titanium contacts on cubic boron nitride thin film as a function of furnace temperature (measured on heating).
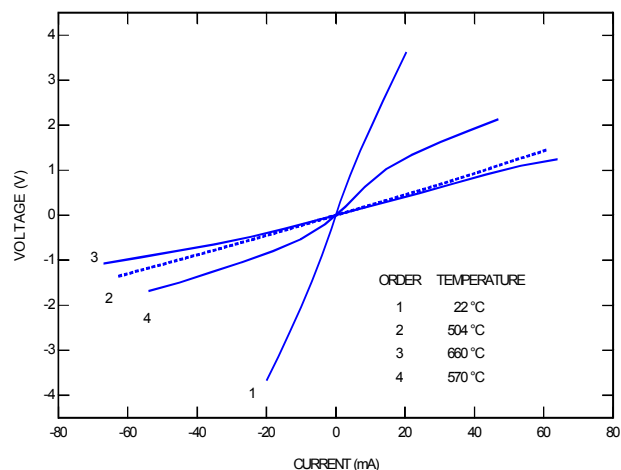
Figure 2. Current versus voltage curves measured between two silver/tungsten/titanium contacts on cubic boron nitride thin film (measured during the furnace heating/cooling cycle at the indicated temperatures and in the order given.

The four-probe sample was mounted in a project-designed and built sample probe for measuring carrier transport properties over a wide temperature range. Room temperature values of conductivity and Hall mobility of 166 ● $^{-1}$ cm^{-1} and 200 cm^2 V^{-1} s^{-1}, respectively, were obtained for a 670Å-thick c-BN film (without consideration of any size effects).

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Detection of Ionic Nutrients in Aqueous Environments by Using Surface-Enhanced Raman Spectroscopy

Dr. Pamela A. Boss
D363, (619) 553–1603

For the Navy, information on nutrient dynamics is useful to understand chemical reactions that impact marine environmental quality and to predict the distribution, growth, and community structure of biota in the coastal ocean. There currently exists no technology capable of detecting ionic nutrients simultaneously, in-situ, in real-time, with little or no sample preparation, and in the ppb–ppm concentration range. To address this need, we proposed the use of cationic-coated, silver surface-enhanced Raman spectroscopy (SERS) substrates. We demonstrated that, using this technology, we can detect nitrate and sulfate in aqueous environments in the ppm concentration range. By using longer acquisition times, ppb detection is possible. We developed a means of adhering thin gold and silver films (<50 nm) on glass while retaining the SERS response. We also evaluated the response of the cationic-coated SERS substrates to chloride-ion and showed that chloride is an interference. However, this interference can be removed by using cationic-coated silver (IC-Ag) solid-phase extraction (SPE) cartridges prior to SERS analysis.

For the Navy, information on nutrient dynamics is useful to help understand chemical reactions that impact marine environmental quality and to predict the distribution, growth, and community structure of biota in the coastal ocean. Additionally, these ionic nutrients impact the environment and are responsible for eutrophication of ponds and lakes and for the increased, worldwide incidences of harmful algael blooms. A need exists for a sensor to monitor these ionic pollutants continuously, simultaneously, in real time, *in-situ*, and with little or no sample preparation. Such a sensor must be able to differentiate the ionic species, not suffer from interferences, be able to detect ppb–ppm concentrations of the anions, and be reversible. A number of technologies have been tried, including colorimetry, ultraviolet visible (UV-VIS) absorption spectroscopy, normal Raman spectroscopy, potentiometry using ion-selective electrodes, and ion-exchange chromatography. However, these approaches do not meet all the desired criteria of specificity, sensitivity, real time, etc. To meet this need, we are developing cationic-coated, silver substrates to detect anionic nutrients in aqueous environments by surface-enhanced Raman spectroscopy (SERS). There are cationic thiols commercially available. After the silver electrodes have been electrochemically roughened, they are reacted with alcoholic thiol solutions to form a self-assembled monolayer (SAM). Since the SAM is positively charged, it attracts negatively charged ions, which are then identified and quantified by their SERS response.

Previously, we demonstrated that using cationic-coated, silver SERS substrates, we can detect nitrate and sulfate in the ppm concentration range. By using longer integration times, ppb detection was possible. The adsorption of the anions onto the coatings were described by a Frumkin isotherm:

$\theta = \dfrac{cKe^{2g\theta}}{1 + cKe^{2g\theta}}$, where θ is the fractional coverage of the anion on the coating, c is the anion solution concentration, K is the ion-pair formation constant, and g is the Frumkin parameter. We also developed a means of adhering thin gold and silver films (<50 nm) on glass, while retaining the

SERS response. The use of thin metal films allows one to acquire data using the "backside" configuration. In the backside approach, the laser light is focused through the thin metal film onto the coated surface that is exposed to the sample. Because laser light does not appreciably pass through a liquid film, any fluorescence is minimized as well as attenuation of the near infrared (IR) excitation by the water. The approach developed uses (3-mercaptopropyl)-trimethoxysilane (MCTMS) to bind the metal film to chemically etched glass. The etched glass provides the roughness features necessary for a SERS response.

We evaluated the response of the cationic-coated SERS substrates to chloride-ion. Figure 1 summarizes the spectral response and shows a plot of nitrate-ion peak area as a functon of chloride-ion concentration. As the chloride-ion increases, the nitrate peak area decreases, then levels off. The results summarized in figure 1 indicate that chloride-ion interferes in the detection of these anions. The results also indicate that both chloride and nitrate are competing for the same sites on the cationic coating. Chloride-ion does not exhibit a Raman active peak, so the ion pair constant between chloride and the cationic coating cannot be measured directly. However, as a result of competitive complexation between chloride and nitrate, it is possible to extract the ion pair formation constant between chloride-ion and the coating by using the nitrate response. The nitrate peak-area response shown in figure 1 is described by $\Delta A_{NO3} = \dfrac{V c_{Cl}}{K + c_{Cl}}$ where ΔA_{NO3} is the change in the nitrate peak area and c_{Cl} is the chloride-ion concentration in solution. From K, and knowing the ion pair formation constant between nitrate and the cationic coating and nitrate-ion concentration, the value of the chloride-ion pair formation constant can be calculated. To remove the chloride-ion concentration, we are looking at solid-phase extraction (SPE) cartridges. There are commercially available SPE cartridges designed to remove chloride-ion interferences. These cartridges contain a sulfonic-acid cation resin in the silver form. They remove chloride-ion interference by precipitating out silver chloride.
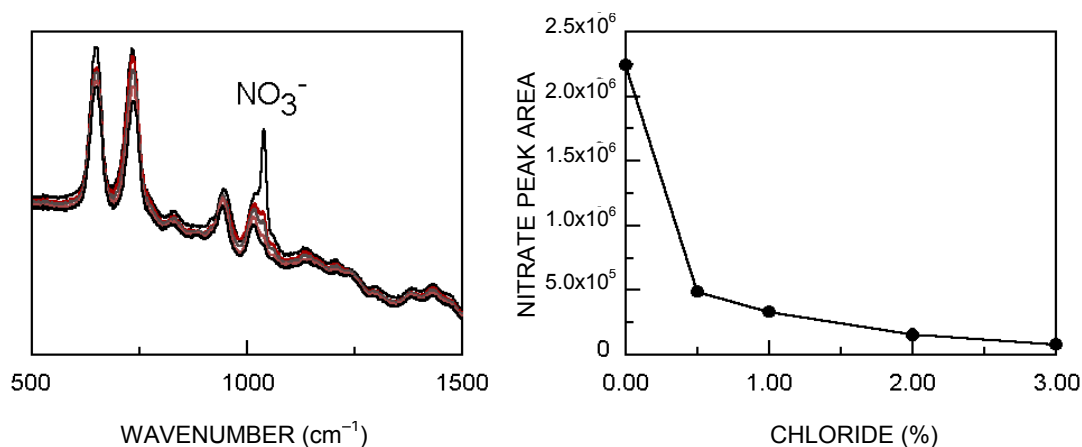
Figure 1. Summary of the SERS response of the Ag/cysteamine hydrochloride/nitrate system as a function of chloride-ion concentration. Nitrate-solution concentration is 1000 ppm.

Figure 2 summarizes the results obtained using the SPE cartridges to remove chloride-ion. Not only did the cartridges remove the chloride-ion, but they also enhanced the signals due to nitrate and sulfate (sulfate is a low ppb contaminant in the sodium chloride used in these experiments). Further measurements indicated that free silver ion from the cartridges was present in the filtrate. The silver

photo-reduces to form a colloid. The colloidal particles are very attractive to anions and would essentially form a large polyanion, which would then interact with the coated substrates. The resultant enhancement in the signal for the anions results from preconcentration of the anions on the colloidal particles, as well as a SERS enhancement due to the colloid itself.
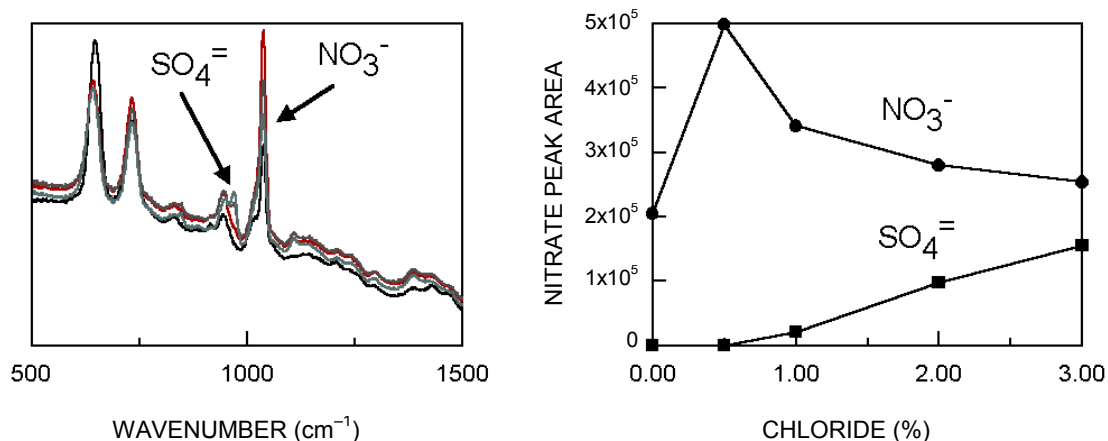
Figure 2. Summary of the SERS response of the Ag/cysteamine hydrochloride/nitrate system as a function of chloride-ion concentration after removal of chloride-ion interference by using SPE cartridges. Nitrate-solution concentration is 1000 ppm.

Antijam Techniques for GPS Utilizing Nonlinear Processing

Dr. Howard L. Dyckman, D313, (619) 553–3829
Richard H. Patterson, formerly at SSC San Diego
Harper J. Whitehouse, Linear Measurements, Inc., San Diego

This project's objective was to study and demonstrate the use of advanced nonlinear signal-processing techniques to decrease the jammer/signal ratio in the receiver for within-band jamming of the Global Positioning System (GPS) signal. Nonlinear signal-processing techniques were studied to develop a method of protecting GPS receivers from strong within-band jamming by accidental and intentional narrowband and/or wideband interference. These techniques employed a nonlinear operation that suppresses the GPS signal relative to the jammer; the result of this operation was subtracted from the original signal to achieve suppression of the jammer. Both memory-less techniques and memory-employing techniques were considered. During FY 00, the investigation results were ambiguous, and a definitive answer regarding the feasibility of the proposed techniques could not be established. Therefore, simulation of the signal-reconstruction technique that combines both the memory and memory-less elements of the program will continue.

BACKGROUND

Global Positioning System (GPS) receivers are vulnerable to jamming, particularly since the GPS signals are much weaker than the ambient noise. The objective of this project was to develop nonlinear techniques that could be applied before the receiver to decrease the jammer/GPS-signal ratio.

Hard-limiting has been shown to widen the gap between a strong jammer and a weak signal [1–4]. Similar suppression of a weak signal occurs in a coarse A-D converter or quantizer when the stronger of the signals captures the dynamic range of the quantizer. Since, by design, the GPS signal is weaker than the noise, and, by definition, the jammer is stronger than the noise, the coarse quantizers used in commercial military GPS receivers suppress the desired GPS signal when a strong jamming signal is present.

APPROACH

Simulations were performed in which a binary pseudonoise code (to represent a weak GPS signal from a single satellite), Gaussian noise, and a strong jammer waveform were summed. Nonlinear operations were performed on that summed waveform in an attempt to reduce the strength of the jammer and, thereby, improve detection of the GPS signal. Assuming that the nonlinear operation would leave the jammer enhanced relative to the GPS signal, the result of the nonlinear operation was subtracted from the original signal. Simulations were also done to determine the signal-to-noise (SNR) performance of the pseudorandom (PN)-sequence correlator, which detects the GPS signal following the nonlinear antijam (AJ) processing.

An alternative architecture using a feedback approach similar to [5] was considered but not simulated, because, in this application, the feedback would have complicated the implementation without enhancing the nonlinear processing being performed.

RESULTS

When the jammer was a binary-valued waveform, a memoryless coarse quantizer was able to separate jammer and GPS signal and thus enabled subtracting off much of the jammer signal.

When the jammer was a sum of sinusoids, the nonlinear processing by using a coarse quantizer suppressed both the jammer and the GPS signal. The nonlinear processing usually suppressed the jammer more than the GPS signal. However, the processing introduced a strong new interference that negated the benefit of the suppression of the jammer. It was proposed that this interference was a form of quantization noise. Smooth nonlinearities were then substituted for the coarse quantizer, but the result was similar.

It had been expected that simulation would quickly show that the method was viable, and construction of circuitry to demonstrate this nonlinear AJ concept at baseband had been planned. Since the technique as originally formulated did not work in simulation, no circuitry was built. The simulation of correlator SNR is waiting a determination of revised architecture and parameters.

A revised signal -processing technique that uses memory in the form of past values of the input signal is expected to average out the quantization and signal-processing noise. This technique will be more complex to implement. In [6–11], it is shown that a baseband random process whose spectral density is bounded in an interval "can be extrapolated ahead as far as we please." In the course of this ILIR program, we have shown how to apply that result to a random process that has been filtered with an arbitrary impulse response. In this case, the signal can be extrapolated as far ahead as the effective duration of the impulse response of the filter. Then, using a weakly nonlinear analysis technique based on regularized deconvolution of the filter's impulse response [12], we expect to recover the extrapolated signal in a manner that minimizes the mean-squared reconstruction error. The reconstructed signal would then be subtracted from a quantized version of the input signal with the anticipated result of reducing the jamming signal with only a small reduction in the GPS signal.

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Laser Optical Parametric Oscillator for Mid-Infrared

Joseph F. Myers
D743, (619) 553–2599

This ILIR project was designed to demonstrate a laser-pumped optical parametric oscillator (OPO) tunable in the 2.5- to 5.0-µm wavelength band. An intracavity laser-pumped OPO using Ti:Al₂O₃ (Ti:Sapphire) as the pump source and potassium titanyl arsenate (KTA) as the OPO was designed. The KTA was cut for type II noncritical phase-matching. Tuning of the laser could therefore be accomplished by rotation of the intracavity birefringent filter (BRF). Continuous wave (CW) output was demonstrated by monitoring the OPO signal. Various weapons use mid-infrared (mid-IR) emissivity as a guide to their target. This program seeks to develop a directional mid-IR source as an IR countermeasure.

SUMMARY

Optical parameter oscillators (OPOs) pumped by either continuous wave (CW) lasers such as Nd:YAG (Neodium: yttrium aluminum garnet) [1] or self-mode locked lasers such as Ti:Sapphire [2] have produced outputs in the 1.0- to 5.0-µm wavelength range with output conversion efficiencies of up to 30%. However, the nonlinear crystals used have poor resistance to damage and have high sensitivity to thermal loads. Although demonstrated in the past, laser-pumped OPOs have yet to be proven reliable in power and tunability. By nature, the nonlinear OPO crystal operates best at high temperatures—thus the need for a robust material. At present, much work is being done to manufacture materials that are both robust and broadly tunable.

An intra-cavity laser pumped OPO is the current configuration being used. This design allows the OPO to see much higher energy densities than could be obtained with an external cavity design. In the case of a Ti:Sapphire laser operating at 4.2 W with an output coupling of 10%, the intracavity circulating power is roughly 40 W. This design should, therefore, produce outputs an order of magnitude greater than an external cavity laser-pumped OPO. The laser pump source is a Ti:Sapphire laser pumped with an Ar⁺ laser. Ti:Sapphire was selected as the pump source because of its broad tunability. A birefringent filter (BRF) is used to tune the output. It is important to note that by using a non-critically phase-matched OPO, tuning is accomplished by tuning the resonant frequency of the Ti:Sapphire crystal by rotating the BRF. Therefore, this design is not only unique in that the OPO exploits the circulating power, it is also unique because tuning is accomplished with the BRF. The FY 99 proposal stated that the OPO crystal would be silver gallium sulfide (SGS). However, due to cost and availability issues, KTA has been substituted as a first step in demonstrating the concept. KTA is much less expensive and is widely available. The major issues to be addressed with this resonator design, including tunability, efficiency, and suitable output power, can be accomplished much more cost effectively with KTA.

A performance evaluation is currently underway and should be completed in FY 01. Upon completion of the measurements using KTA, silver gallium sulfide will be substituted in the laser cavity. SGS has the promise of obtaining the desired bandwidth and power requirements necessary to make it a viable candidate for mid-IR countermeasures.
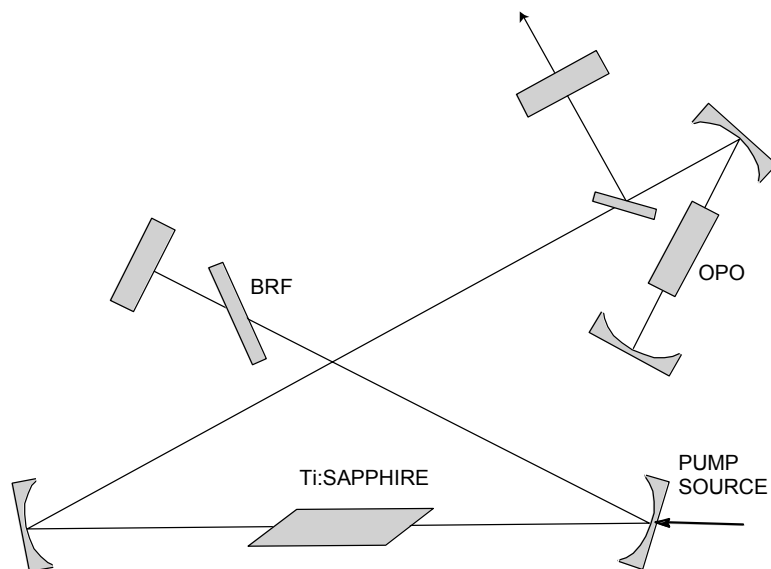
Figure 1. Configuration for intracavity laser-pumped OPO using Ti:Sapphire.

EO countermeasures are important for the Navy, Air Force, and commercial aviation. A working tunable mid-IR laser OPO could be mounted to an aircraft in order to confuse an incoming missile that is trained to detect targets in that bandwidth.

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PROGRAM IMPACTS

PROGRAM IMPACTS

By definition, ILIR is focused on discovery and invention—the earliest phases of innovation. For such basic research to impact the Fleet and Force, years to decades of development and trial are typically required. Since ILIR projects are usually closely associated with pressing Navy needs, this time to impact Fleet introduction is often somewhat shorter. However, in general, the ILIR results of today will not impact Fleet and Force capabilities until well into the 21st century. Thus, the impact of a single year of ILIR work can only be estimated. Two concrete measures and one speculative measure are thought to be appropriate for this purpose, and we have included a few examples for each of these measures. Section 1 includes examples of significant scientific and technology accomplishments resulting from the FY 00 ILIR program. Section 2 describes examples of the transitions of the FY 00 ILIR efforts to other, more advanced, funding categories. Section 3 provides speculative examples as to how promising results of the program may benefit the Fleet if these results are successfully developed and transitioned.

Another way to assess potential impact is by looking at how ILIR projects relate to the principal constituents of DoN systems. Figures 1 and 2 show this relationship.

Figure 1. FY 00 ILIR potential impacts for ships.
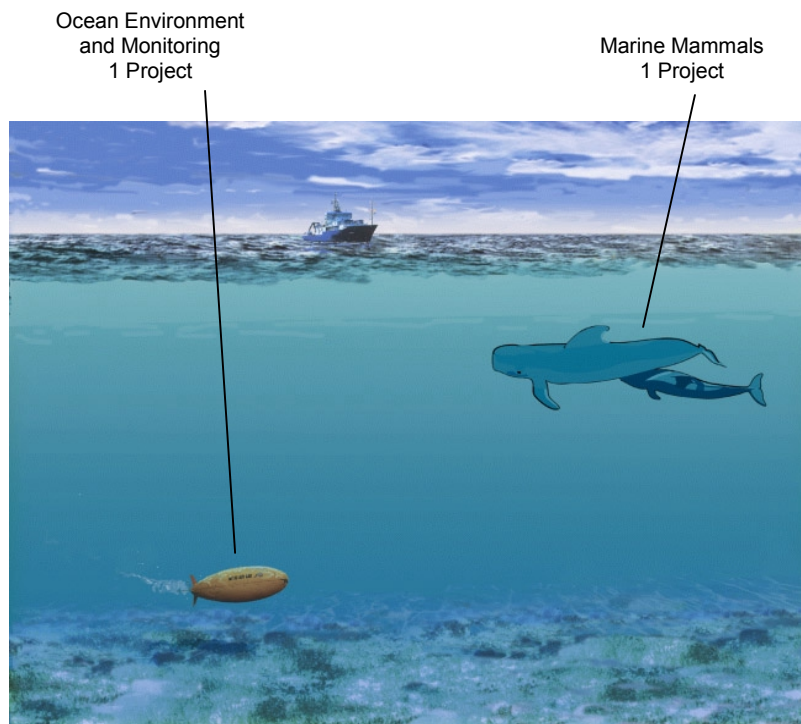
Figure 2. FY 00 ILIR potential impacts for the marine environment.

1. EXAMPLES OF SCIENTIFIC AND TECHNICAL ACCOMPLISHMENTS

Sensitivity of Marine Mammals to Low-Frequency Acoustic Pressure and Particle Motion

Dr. Sam Ridgway, SSC San Diego, D35
(619) 553–1374

Concern that man-made noise in the ocean may compromise the hearing or affect the behavior of marine mammals has given rise to legal actions that have resulted in costly delays and expensive modification to Navy projects. In addition, the discovery of dead whales often brings into question possible involvement of human activities, especially naval activities, in causing the mortality. At present, there is a critical lack of knowledge on which to base decisions concerning the effects of underwater sound on marine species, including whales, dolphins, and sea lions. Prior to this project, there was a near total lack of information concerning the possible effects of acoustic particle motion (i.e., displacement, velocity, or acceleration) on marine mammals.

The relative contributions of acoustic pressure and particle velocity to the low-frequency, underwater hearing abilities of the bottlenose dolphin (*Tursiops truncatus*), white whale (*Delphinapterus leucas*), and California sea lion (*Zalophus californianus*) were investigated by measuring hearing thresholds while manipulating the relationship between the acoustic pressure and particle velocity. This study was accomplished by (1) varying the distance within the nearfield of a single underwater sound projector and (2) using two underwater sound projectors and an active sound control system. Animal subjects were trained to station on an underwater biteplate and participate in hearing tests in which they produced audible responses to tone + noise trials and remained silent during noise-only trials. Stimulus intensity was adjusted (while maintaining the pressure/velocity relationship) by using a

modified staircase procedure. Custom software was developed to calibrate the acoustic system, conduct hearing tests, and analyze the resulting data. Masked hearing thresholds were measured at 100 and 300 Hz by using a single projector at 1, 2, and 4 m and at 300 Hz by using the active control system. The data obtained indicate a lack of particle motion sensitivity in the dolphin and white whale. Results from this FY 99 and FY 00 research were reported via one invited presentation, four contributed presentations, and three refereed journal articles.

Adaptive Stochastic Mixture Processing for Hyperspectral Imaging

Dr. David Stein, SSC San Diego, D743
(619) 553–2533

Understanding the effect of pre-processing transforms on signal detectability is crucial to the successful application of hyperspectral technology. For example, the Naval EarthMap Observer (NEMO) satellite proposes to use a form of vector quantization onboard prior to downloading the imagery. Additionally, we are currently exploring the application of these techniques to radar and communications. The ideas developed during this project will lead to significant improvement in target detection from hyperspectral imagery.

This work has focused on two aspects of the processing of hyperspectral imagery. By reducing the dimension of the data while preserving the signal-to-noise ratio (SNR), anomaly detection can be improved by up to 5 or more dB, depending on the dimensionality reduction achieved, the SNR, and the probability of false alarm (PFA). We have developed a class of transforms that preserve SNR for signals contained within a subspace. We have developed what we call the signal-subspace preservation (SSP) algorithm and a whitened vector quantization (WVQ) transform such that the relative or absolute loss in SNR from applying the transform is less than or equal to a selected upper bound. Data analysis shows that the WVQ and SSP techniques can have much better signal-preserving characteristics for a given reduction in dimension than either the vector-quantization or principal-component transforms. We have also extended multivariate classification techniques to compositional data. The response from each pixel is modeled as a linear combination of samples such that each sample emanates from a multivariate normal distribution. The maximum likelihood equation is solved to estimate the abundance and contribution of each class at each pixel. Preliminary results show that if the classes have sufficient variability, then detection algorithms derived from the stochastic unmixing model have superior performance to those derived from the deterministic mixture model.

Results from this research have been presented at four conferences with accompanying papers in the refereed conference proceedings. Four journal publications are in preparation, and four patent disclosures will be submitted.

Robust Waveform Design for Tactical Communications Channels

Dr. James Zeidler, SSC San Diego, D8505
(619) 553–1581

The project objective is to develop the analytical tools that are required to evaluate the tradeoffs in data rate and security that are fundamental to the design of robust tactical communications networks. The critical parameters of the system are the waveform design, the transmitter and receiver antenna

gain and directivity, the interference parameters, and the characteristics of the tactical communications channel. Our approach has been to define the bit-error rates of several candidate waveforms as a function of the energy per bit, the number of bits per symbol, and other key signaling waveform parameters for candidate transmitter/receiver architectures. This analysis permits the evaluation of the tradeoffs in data rate and detectability of the transmitted waveforms. Nonlinear adaptive signal-processing techniques are being developed to mitigate the effects of hostile interference. This project addresses current naval needs for tactical littoral communications for the Marine Corps 2010 Communications Architecture for Operational Maneuvers from the Sea.

Major results to date include the development of analytical tools that accurately predict the performance of prototype low-probability-of detection (LPD) waveforms. A second major result was the development of nonlinear signal-processing techniques that have been shown to maximize interference suppression with minimal distortion of the desired signal waveforms.

Prior to the beginning of this effort, there was a pre-existing ONR 313 6.2 effort in LPD radio technology that implemented a prototype receiver. That project has used results from this effort. In addition, a new SSC San Diego effort in LPD tactical sensors has been funded by the Defense Threat Reduction Agency (DTRA) in FY 01. Dale Bryan, D371, leads this task and an existing SSC San Diego effort in tactical surveillance sensors (funded by the Army). Dale Bryan also leads the Cooperative Research and Development Agreement (CRADA) with Harris/Intersil on the development of LPD capability for the PRISM chip set. Results from this task will be integrated into the CRADA. Current software-controlled radio projects such as Defense Modular Radio (DMR) and the Joint Tactical Radio System (JTRS) will provide an efficient way to introduce new waveforms into the tactical radio networks.

Results from this research are reported in six refereed publications (two published, four submitted), one invited presentation, one technical report, and one thesis dissertation. This is a team project, and one of the team members, Dr. Mike Reuter, received his Ph.D. in July 2000.

2. EXAMPLES OF TRANSITIONS INTO OTHER PROGRAMS

Sonar Waveform Design

Mr. James Alsup, SSC San Diego, D711
(619) 553–2498

The project objective of the Sonar Waveform Design was to improve current Doppler-sensitive waveform capability through the derivation and implementation of new power-efficient, Doppler-and-range resolving waveforms. The approach was two-fold: first, design the "Triplet-Pair" waveform to improve efficiency in using the sonar projector, and second, design the "Hermite Function Space" waveform and the associated "Constrained, Regularized Deconvolution" processing method to achieve unparalleled Doppler sensitivity for use in littoral antisubmarine warfare (ASW).

A patent application was submitted for the "Triplet-Pair" waveform, and papers covering both tasks were presented at scientific meetings and seminars. We believe the technology developed in this project will support active sonar used in naval surveillance and tactical systems designed for use in littoral waters, where good Doppler-sensitive waveforms are becoming more important in the

requirement to reach into the very-low Doppler regime where enemy submarines can otherwise hide undetected.

The ONR research community, specifically the Multistatic ASW Capability Enhancement (MACE) program, will use these new waveforms during one of the littoral warfare advanced development (LWAD) tests where MACE is deployed. The waveforms will also be used by the Space and Naval Warfare Systems Command's (SPAWAR's) low-frequency active/surveillance towed array sensor system (LFA/SURTASS) program, by NAVAIR's Air-Deployable Low-Frequency Projector (ADLFP) program, and would generally be used in most naval sonars operating at frequencies below 5 kHz.

Detection of Ionic Nutrients in Aqueous Environments Using Surface-Enhanced Raman Spectroscopy (SERS)

Dr. Pamela Boss, SSC San Diego, D363
(619) 553–1603

For the Navy, information on nutrient dynamics is useful in understanding chemical reactions that impact marine environmental quality and in predicting the distribution, growth, and community structure of biota in the coastal ocean. There currently exists no technology capable of detecting ionic nutrients simultaneously, *in situ*, in real time, with little or no sample preparation, and in the ppb-ppm concentration range. To address this need, we investigated the use of cationic-coated, silver SERS substrates. We demonstrated that, by using this technology, we can detect nitrate and sulfate in aqueous environments in the ppm concentration range. By using longer acquisition times, ppb detection is possible. We developed a means of adhering thin gold and silver films (<50 nm) on glass while retaining the SERS response.

We received funding from the Naval Facilities Engineering Command (NAVFAC) to apply this technique to the Navy's Methyl tert-butyl ether (MTBE) problem. MTBE is an additive in gasoline and is a mobile contaminant and a bigger threat to groundwater than petroleum hydrocarbons. NAVFAC has funded SSC San Diego with $25K in FY 01 for bench-scale testing of the proposed SERS sensor. If testing is successful, NAVFAC will fund the development of a field-deployable MTBE sensor in FY 02 and FY 03.

Environmental Adaptive Matched-Field Tracking

Dr. Homer Bucker, SSC San Diego, D857
(619) 553–3093

The project objective was to demonstrate automatic detection of a submarine in a littoral environment by using an inexpensive deployable line array of hydrophones. This study was done by finding a target track that had the highest value of matched-field correlation for a 3- to 5-minute period. The depth of the track is the discriminate used to separate submarines from surface ships. In FY 99, a six-element vertical-line array was used to detect targets in a shallow-water area close to San Diego. In FY 00, work focused on developing algorithms for use with a six-element bottom-line array in the Adriatic Sea, as part of the Remote Deployable Systems (RDS-3) experiment. Good results were obtained from a preliminary test in local waters.

Funds to transition this work to a practical system have been obtained from the Deployable Autonomous Underwater Systems (DAUS) program, ONR-321 SS.

Integration of Complex Information

Mr. Douglas Lange, SSC San Diego, D4223
(619) 553–6534

The project objective is to define a mechanism to allow complex nonspecified information to be integrated and used. The method being explored uses open hypermedia architectures and lightweight inference to manage and utilize information. Successes to date include the definition of a hypermedia framework that can be used for intelligence analysis and plan description and tracking, identification of two inference strategies to be explored, and the successful transition of the hypermedia framework to a development project. The emphasis for FY 01 is on implementing and evaluating the inference strategies and demonstrating the ability to infer some information from the hypermedia framework.

This project has transitioned into the following efforts and programs:

1. Defense Intelligence Agency (DIA) funded an effort to implement the results of this research in a project titled "Military Operations in Built-up Areas." The system into which the transition occurred is called "KnowledgeNet." KnowledgeNet is an intelligence analysis system. (Customer order CC174M0R, $358K)

2. SPAWAR PD-13 via SSC San Diego D10, funded an effort to begin transitioning KnowledgeNet into a Global Command and Control System–Maritime (GCCS–M) segment. (Project number unknown, $70K)

3. The National Ground Intelligence Center is expected to provide $290K in funding during FY 01 to continue KnowledgeNet development.

4. Results from this ILIR project are to be transitioned into the information architecture of the Theater Battle Command and Control project sponsored by ONR (CDB34R1F and CDB34X1F, $850K per year, FY 01 through FY 03).

Applications of Stochastic Nonlinear Dynamics to Communications Arrays

Dr. Brian Meadows, SSC San Diego, 364
(619) 553–2823

This research studied two effects—nonlinearity and coupling—with the goal of developing dynamic nonlinear antennas. The project leveraged recent advances in active antenna design and the theory of non-identical oscillators to generate beam steering and beam forming across the array of nonlinear oscillators. Merging nonlinear dynamics and radio frequency (RF) microelectronics creates an antenna design capable of providing a significant level of directivity in a small volume. Project results have significant applications in defeating jamming of global positioning system (GPS) signals as well as in communications and surveillance systems.

Results from the project have transitioned into the following FY 01 programs: (1) A joint Chief Technical Officer (CTO), ONR, and PMW/A-187 sponsored project, "Nonlinear GPS Antenna Technology," $5.4M over 3 years (anticipated award of $5.4M would include a $500K contract from

ONR 313 listed below); (2) a NAVAIR, PMA-264 project, "Nonlinear Multi-Element Apertures," $700K (FY 01 anticipated); (3) $465K (N66001RC00-00220; 6389 Task 3) covering 6.2/6.3 research applications to active deployable acoustic research (ADAR) sonobouy arrays; and (4) an ONR 313 project, "Nonlinear GPS Technology," $500K (MA233R1A01), covering 6.2 research for GPS antennas.

Laser Optical Parametric Oscillator for Mid-IR

Mr. Joseph Myers, SSC San Diego, D743
(619) 553–2599

Various weapons use mid-infrared (mid-IR) emissivity as a guide to their target. The objective of this project was to develop a directional mid-IR source as an infrared countermeasure. We demonstrated a laser-pumped optical parametric oscillator (OPO) tunable in the 2.5- to 5.0-µm wavelength band. We designed an intracavity laser-pumped OPO using Ti:Sapphire (Ti:Al2O3) as the pump source and potassium titanyl arsenate (KTA) as the OPO. The KTA was cut for type II noncritical phase matching. Tuning of the laser could therefore be accomplished by rotation of the intracavity birefringent filter (BRF). Continuous-wave (CW) output was demonstrated by monitoring the OPO signal. This program transitioned to the Navy's frequency agile infrared laser system (FAIRLASS).

3. EXAMPLES OF POTENTIAL FLEET IMPACTS

All projects listed in the two preceding sections, "Examples of Scientific and Technical Accomplishments" and "Examples of Transitions into Other Programs," have the potential to make significant impacts on fleet capabilities. These potential impacts are summarized below.

The **Sensitivity of Marine Mammals to Low-Frequency Acoustic Pressure and Particle Motion** project will benefit the Fleet by providing essential information to enable testing and use of active sonar systems without endangering marine mammals.

The **Adaptive Stochastic Mixture Processing for Hyperspectral Imaging** project promises to improve target acquisition by increasing the usability of hyperspectral image data to identify concealed targets.

The **Robust Waveform Design for Tactical Communications Channels** project will provide the science to enable technology for covert communications fleet littoral warfare and Marine Corps (MARCOR) expeditionary operations. It will also improve the technology for communications in the presence of strong interference.

The **Sonar Waveform Design** project will improve underwater surveillance by developing more efficient and effective waveforms for active sonar signals.

The **Detection of Ionic Nutrients in Aqueous Environments by Using Surface-Enhanced Raman Spectroscopy (SERS)** project promises to save money in Navy operations by enabling more cost-effective methods for detecting environmental contaminants. Such methods will help in both prevention and remediation of environmental impacts by Navy operations.

The **Environmental Adaptive Matched-Field Tracking** project is directed to improving the science and technology needed to automatically detect and track submarines in the littoral environment. Progress in the science underlying the technology will help address this critical Navy need.

The **Change Blindness: Understanding Our Visual Representation of Objects and Scenes** project is aimed at increasing the effectiveness of personnel who observe and monitor information displays. Future naval information and control workstations will provide large, physically dispersed, screen areas that will require operators to shift their attention from one display to another—a departure from current "single task/single display" command and control consoles. This diversion of attention creates an opportunity for changes to be made to unattended screens. The result is that operators may suffer from "change blindness," which could have potentially disastrous consequences. The science resulting from this project should help in designing display systems less vulnerable to such catastrophic outcomes.

The **Integration of Complex Information** project has already transitioned into projects to improve the information architecture of systems employing hypermedia data. The capability to effectively use hypermedia will be essential in future control systems.

The **Applications of Stochastic Nonlinear Dynamics to Communications Arrays** project addresses the Navy need for smaller and more capable antennas. As one important example, the results from the project are expected to have significant applications in defeating the jamming of GPS signals. The capability for GPS operation despite jamming will be extremely important for guided weapons and for MARCOR forces on the battlefield.

The **Laser Optical Parametric Oscillator for Mid-IR** project is directed to producing tunable infrared sources that can be used for IR countermeasures. Tunable IR sources are needed to protect Navy assets by confusing or disabling IR-directed weapons or surveillance.

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Meadows, B. K. 2000. "From Theoretical Musing to Fleet Applications," invited seminar, Defense Advanced Research Projects Agency, 15 September and 19 October, Arlington, VA.

Meadows, B. K. 2000. "Chaos in San Diego: Nonlinear Dynamics Research at SSC San Diego," invited seminar, 18 September, Program Executive Office, Air.

Meadows, B. K. 2000. "Navigation Warfare Modernization," invited seminar, Naval War College, 28 September, Newport, RI.

Milanova, M., A. Elmaghraby, and S. H. Rubin. 2000. "Cellular Neural Networks for Segmentation of Image Sequence," 9th International Conference on Intelligent Systems, 15 to 17 June, Louisville, KY.

Mosier–Boss, P. A. and S. H. Lieberman. 1999. "The Use of Cationic-Coated, Silver SERS Substrates to Detect Ionic Nutrients in Aqueous Environments," Electrochemical Society Meeting, 17 to 22 October, Honolulu, HI.

Mosier–Boss, P. A. and S. H. Lieberman. 2000. "Detection of Anionic Nutrients Using Cationic-Coated, Silver SERS Substrates," On-Site 2000 Conference, 23 to 26 January, Las Vegas, NV.

Mosier–Boss, P. A. and S. H. Lieberman. 2000. "Environmental Applications of Thiol-Coated SERS Substrates," invited presentations at the 219th National American Chemical Society Meeting, 26 to 30 March, San Francisco, CA.

Murray, S. 1998. "Operator Alertness and Human–Machine System Performance During Supervisory Control Tasks," Third Automation Technology and Human Performance Conference, 25 to 28 March, Norfolk, VA.

Murthy, J. and S. H. Rubin. "Multi-Sensor Fusion for Photonic Realization," 1st Annual Information Integration and Reuse Conference, November, Atlanta, GA.

Oliver, C. W., J. J. Finneran, and K. M. Schaefer.1999. "Low-Frequency Acoustic Detection of Yellowfin Tuna, *Thunnus albacares*, and Possibly Dolphins by Yellowfin Tuna, in the Eastern Tropical Pacific Ocean," 13th Biennial Conference on the Biology of Marine Mammals, 29 November to 3 December, Maui, HI.

Porter, M. B., V. K. McDonald, P. A. Baxley, and J. A. Rice. 2000. "Relating the Channel to Acoustic Modem Performance," Fifth European Conference on Underwater Acoustics (ECUA 2000), 10 to 13 July, Lyons, France.

Porter, M. B., V. K. McDonald, P. A. Baxley, and J. A. Rice. 2000. "SignalEx: Linking Environmental Acoustics with Signaling Schemes," Oceans 2000 MTS/IEEE (Marine Technology Society/ Institute of Electrical and Electronics Engineers), 11 to 14 September, Providence, RI.

Porter, M. B., V. K. McDonald, J. A. Rice, and P. A. Baxley. 2000. "Relating Modem Performance to the Ocean Channel Properties," 139th Meeting of the Acoustical Society of America, 30 May to 3 June, Atlanta, GA.

Reuter, M., K. Quirk, J. Zeidler, and L. Milstein. 2000. "Nonlinear Effects in LMS Adaptive Filters," invited presentation at Symposium 2000 on Adaptive Systems for Signal Processing, Communications, and Control (AS-SPPC), sponsored by the Institute of Electrical and Electronics Engineers (IEEE), 1 to 4 October, Lake Louise, Alberta, Canada.

Rice, J. A. 2000. "Telesonar Signaling and Seaweb Underwater Wireless Networks," NATO Research and Technology Agency Symposium on New Information Processing Techniques for Military Systems, 9 to 11 October, Istanbul, Turkey.

Rice, J. A., B. Creber, C. Fletcher, P. A. Baxley, K. Rogers, K. McDonald, M. Wolf, S. Merriam, R. Mehio, J. Proakis, K. Scussel, D. Porta, J. Baker, J. Hardiman, and D. Green. 2000. "Evolution of Seaweb Underwater Acoustic Networking," Oceans 2000 MTS/IEEE (Marine Technology Society /Institute of Electrical and Electronics Engineers), 11 to 14 September, Providence, RI.

Rubin, S. H. 1999. "Relaxed Fuzzy Randomization," invited presentation at the 18th Annual Meeting of the North American Fuzzy Information Process Society (NAFIPS), 10 to 12 June, New York, NY.

Rubin, S. H. 1999. "The Role of Computational Intelligence in the New Millennium," (plenary) keynote address, 3-D World Multiconference on Systemics, Cybernetics, and Informatics (SCI '99) and 5th International Conference on Information Systems Analysis and Synthesis (ISAS '99), 31 July, Orlando, FL.

Rubin, S. H. 2000. "Data Mining," invited lecture, Department of Computer Science, Saginaw Valley State University, 10 March, Saginaw, MI.

Rubin, S. H. 2000. "Relational Tensors for Conceptual Discovery," 2nd Annual Information Reuse and Integration (IRI) Conference, 1 to 3 November, Honolulu, HI.

Rubin, S. H. and M. G. Ceruti. 2000. "Generalization of Attributes before Mining to Enable Rule Discovery," invited presentation at the 19th International Meeting of the North American Fuzzy Information Processing Society (NAFIPS), 13 to 15 July, Atlanta, GA.

Rubin, S. H., M. G. Ceruti, R. J. Rush Jr. 2000. "Knowledge Mining for Decision Support in Command and Control Systems," invited presentation to the Armed Forces Communications and Electronics Association (AFCEA) 17th Annual Federal Database Colloquium and Exposition, Data Management for the 21st Century, 6 to 8 September, San Diego, CA.

Rubin, S. H., M. G. Ceruti, and L. C. Shen. 2000. "Mining the Web for Knowledge with Sub-Optimal Mining Algorithms," 24th IEEE Computer Society International Conference on Computer Software and Applications (CompSac2000), 25 to 29 October, Taipei, Taiwan.

Rubin, S. H. and R. Lee. 1999. "Randomization and Reuse for Expert Systems," 1st Annual Information Integration and Reuse Conference, November, Atlanta, GA.

Rubin, S. H. and R. Lee. 1999. "Reusable Component Compilers," 17th Annual International Conference of the Association Management and the International Association Management, 6 to 8 August, San Diego, CA.

Rubin, S. H. and M. Milanova. 1999. "Heuristic Search in 3-D Object Recognition," invited presentation at the 3-D World Multiconference on Systemics, Cybernetics, and Informatics (SCI 99) and 5th International Conference on Information Systems Analysis and Synthesis (ISAS 99), 31 July to 4 August, Orlando, FL.

Rubin, S. H. and M. Milanova. 1999. "Heuristic Search in Planning Sequences of Views for 3-D Object Recognition," 1st Annual Information Integration and Reuse Conference, November, Atlanta, GA.

Rubin, S. H., M. Milanova, and A. Campilho. 2000. "Estimating Motion Flow Field in Image Sequences Using Cellular Neural Networks," International Conference on Parallel and Distributed Processing Technology and Application (PDPTA '2000), 26 to 29 June, Las Vegas, NV.

Rubin, S. H., J. Murthy, M. G. Ceruti, M. Milanova, Z. C. Ziegler, and R. J. Rush Jr. 2000. "Third Generation Expert Systems," 2nd Annual Information Reuse and Integration (IRI) Conference, 1 to 3 November, Honolulu, HI.

Rubin, S. H., M. H. Smith, and L. Trajkovic. 1999. "Randomizing the Knowledge Acquisition Bottleneck," invited presentation at the 1999 IEEE International Conference on Systems, Man, and Cybernetics, 12 to 15 October, Tokyo, Japan.

Sritharan, S. S. and J. L. Menaldi. 2000. "Remarks on Impulse Control Problems for Stochastic Navier-Stokes Equations," International Workshop on Differential Equations and Optimal Control, 12 to 14 May, Department of Mathematics, Ohio University, Athens, OH.

Stein, D. W. J. and S. G. Beaven. 2001. "Preprocessing Transforms and Target Detection from Hyperspectral Imagery," Military Sensing Symposium (MSS) Specialty Group on Camouflage, Concealment, and Deception, to be held 5 to 7 March, Tysons Corner, VA.

Stein, D. W. J., S. G. Beaven, and S. Stewart. 2000. "Reduced Dimension Quadratic Detection Algorithms," The International Society for Optical Engineering (SPIE), Imaging Spectrometry VI, 30 July to 4 August, San Diego, CA.

Stein, D. W. J., A. Stocker, and S. G. Beaven. 2000. "The Fusion of Anomaly Detection Statistics," Military Sensing Symposium (MSS) Specialty Group on Camouflage, Concealment, and Deception, 21 to 23 March, Charleston, SC.

Stevenson, J. M. and H. Bucker. 2000. "Matched-Field Processing and Beamforming," 140th Meeting of the Acoustical Society of America, 4 to 8 December, Newport Beach, CA.

Torrez, W. and E. Blasch. 2000. "An Application of Generalized Least Squares Bias Estimation for Over-the-Horizon Radar Coordinate Registration," International Conference on Multisource–Multisensor Data Fusion (FUSION 2000), 10 to 13 July, Paris, France.

Ulieru, M., O. Cuzzani, S. H. Rubin, and M. G. Ceruti. 2000. "Application of Soft Computing Methods to the Diagnosis and Prediction of Glaucoma," IEEE International Conference on Systems, Man, and Cybernetics, 8 to 11 October, Nashville, TN.

HONORS AND AWARDS

HONORS AND AWARDS

Paul Baxley continues as President and Regional Chapter Representative of the San Diego Chapter of the Acoustical Society of America (ASA). He is Chairman of the ASA Public Relations Committee, a Member of the ASA External Affairs Committee, and Co-Chair of the ASA Home Page Committee. He is also a member of the ASA Underwater Acoustics Technical Committee and is a member of the Institute of Electrical and Electronic Engineers (IEEE) Marine Technology Society.

In May 2000, **Dr. George Dillard** served as Chairman, Session on Constant False-Alarm-Rate Processing, for IEEE's International Radar Conference (Radar 2000).

During the May 2000 Principal Investigator Conference in Seattle, **John Drummond** was Co-Chairman of the Defense Advanced Research Projects Agency–Informational Technology Office (DARPA–ITO) Quality of Service Working Group meeting. He was also Co-Chairman of the DARPA–ITO Real-Time NT Operating System Working Group meeting in San Francisco in October 1999.

Dr. I. R. Goodman is serving as ongoing (1995 to present) associate editor of *Information Sciences*. He was also invited to write the preface for the forthcoming book, *Fuzzy Discrete Structures*, by D. S. Malik and J. N. Mordeson.

Frank Hanson is a program committee member for the Military Sensing Symposia (MSS) Specialty Group on Active Electro-Optic (E-O) Systems.

Doug Lange will be the Agencies Liaison Chair and a committee member for the 12th IEEE International Workshop on Rapid System Prototyping (RSP 2001). He was Session Chair for RSP 2000.

John McDonnell serves as an assistant editor for the *IEEE Transactions on Evolutionary Computing* and as the 2nd Vice President for the Evolutionary Programming Society. He also serves as a referee for a multitude of conferences including Parallel Problem Solving from Nature (PPSN), the Congress on Evolutionary Computation (CEC), and the Genetic and Evolutionary Computation Congress (GECCO).

Dr. Brian Meadows is currently providing scientific and technical support to the Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN RDA). He is also the technical team leader of the Global Positioning System (GPS) and Navigation Warfare (NAVWAR) modernization review and reports directly to the ASN RDA. Dr. Meadows also provides scientific and technical support to Chief of Naval Operations (CNO)-N633, Naval Space Systems Division, and he reviews controls on the export of navigation and timing technologies as a consultant to the Military Critical Technology committee.

Joseph Rice is a member of IEEE and ASA and has served as a lecturer for the Physics Department at the Naval Postgraduate School.

Stuart Rubin was elevated to senior membership of IEEE and was the Panel Chair for the session on "Expanding the Meaning of and Applications for Data Mining" at the October 2000 IEEE International Conference on Systems, Man, and Cybernetics, in Nashville, TN. In November, he was

General Chair for the Information Reuse and Integration Conference (IRI 2000) in Honolulu. He was Session Chair at the June 2000 International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA 2000). He will also be Session Chair (Knowledge Discovery) at the June 2001 International Conference on Mathematics and Engineering Techniques in Medicine and Biological Sciences (METMBS '01) to be held in Las Vegas. He also serves as an Associate Editor, *IEEE Transactions on Systems, Man, and Cybernetics (electronic Part B)* at the invitation of L. Hall, Editor-in-Chief.

Dr. Po-Yun Tang served on the Composite Committee of the Material Division of the American Society of Mechanical Engineering (ASME).

Dr. Bruce E. Wahlen served as a consultant to both the Naval Air Warfare Center Aircraft Division and to Rockwell Collins, Inc., during fiscal year 2000 for their combined effort on Bandwidth Efficient Advanced Modulation (BEAM) Technology for UHF SATCOM.

In June 2000, **Dr. James Zeidler** received SSC San Diego's highest honorary award, the Lauritsen–Bennett Award for Achievement in Science. The award was given for his outstanding research, innovation, and technical achievements in the fields of adaptive signal processing and wireless communications networks. In October, Dr. Zeidler served as Chairman, Session on Communications Receivers, for IEEE's Symposium 2000 on Adaptive Systems for Signal Processing, Communications, and Control.

PATENT ACTIVITY

PATENTS ISSUED

Allen Shum   **"Asynchronous Transfer Mode Cell Loss Estimation Algorithms"**

A software program for estimating traffic loss of an asynchronous transfer mode (ATM) statistical multiplexer comprises a communication channel having traffic sources and a buffer. Traffic is generated by the traffic sources and removed by the communication channel. When total traffic exceeds the capacity of the communication channel, excess traffic is stored in the buffer. When the buffer is full, excess traffic is lost. Estimating the amount of traffic that will be lost by an ATM statistical multiplexer, therefore, has application in the design of ATM networks.

Patent 5,963,542 Navy case 77,443 (Serial 08/707,284) filed 3 September 1996; issued 5 October 1999.

Monti E. Aklufi   **"Thin-Film Improvement Method**
Stephen D. Russell   **and Apparatus"**

This invention provides a novel apparatus and an improved method by using a contoured laser beam to improve the electrical, optical, and material properties of thin films.

Patent 6,014,944 Navy case 77,921 (Serial 08/934,037) filed 19 September 1997; issued 18 January 2000.

Willard M. Cronyn   **"Compact, Phasable, Multioctave, Planar, High-Efficiency Spiral-Mode Antenna"**

The antenna consists of eight planar windings, each one of which is an exponential spiral. The windings are connected in groups of three to a balanced transmission line, with a "floating" winding between each of the two groups. For the purpose of phasing elements together for directional-beam control, the particular grouping of windings can be changed. A sinuous variation is imposed on the spiral windings to increase the path length for each winding rotation so that the circumference through which the phase increases by 360 degrees is correspondingly decreased. This element integrates a planar structure, wideband compact design, and phasability into a single physical structure.

Patent 6,023,250 Navy case 76,188 (Serial 09/107,901) filed 18 June 1998; issued 8 February 2000.

David W. J. Stein   **"Hidden-Markov Amplitude Detector"**

This invention provides a means of detecting incoherent signals in non-Gaussian noise.

Patent 6,036,526 Navy case 79,280 (Serial 09/111,369) filed 24 June 1999; issued 14 March 2000.

Gregory A. Theriault
Leonard J. Martini
Leon V. Smith

**"A Translation System
for Directing an Optical Signal
to Predetermined Coordinates"**

A translation system for directing an optical signal through predetermined coordinates of a window mounted in a soil penetration probe includes a tube having a sidewall and an aperture through said sidewall; an optically transparent window mounted in said aperture; an optical system for emitting an optical signal through said aperture; and a translation mechanism mounted within said tube. The translation mechanism may be selectively operated to translate independently and simultaneously the optical system along two orthogonal vectors so that the optical signal scans across the window. Scanning the optical signal extends the useful life of the window before its transmissibility becomes too impaired by damage caused from the optical signal.

Patent 6,046,868 Navy case 78,881 (Serial 09/015,431) filed 29 January 1998; issued 4 April 2000.

Parviz Soltan
John A. Trias
Weldon J. Dahlke
Robert V. Belfatto
Frank Sanzone
Christopher J. Poulos
Neil P. Acantilado

**"Computer-Controlled
Three-Dimensional
Volumetric Display"**

A three-dimensional display system comprises a display volume selectively partitioned into distinct display regions: a display surface for scattering light beams from the display volume; at least two optical scanners for modulating the light beams and for directing the light beams to the display surface within each distinct display region, respectively; and a display controller. The display controller comprises a world-coordinate interface for inputting world coordinates, a data processor for transforming the world coordinates into view coordinates and device coordinates, and an optical-scanner controller for sensing and controlling the motion of the display surface and for outputting the device coordinates to the optical scanners to generate a three-dimensional image within the display volume.

Patent 6,052,100 Navy case 78,445 (Serial 08/926,854) filed 10 September 1997; issued 18 April 2000.

CLAIMS ALLOWED; NOTICE OF ALLOWANCE

Carol A. Becker   **"Light-Activated Polymeric Actuators"**

Visible light causes a pH charge *in situ* to the polymer backbone. The pH charge expands and contracts the polymeric actuator in a timeframe suitable for robotics. A mechanism is provided for reversible dissipation of any heat produced by the light.

Navy case 78,990 (Serial 09/137,008) filed 20 August 1998; Notice of Allowance 24 May 2000.

PATENT APPLICATIONS FILED

Stanislaw J. Szpak
Pamela A. Boss

"Electrode and Method for Preparation of Electrode for Electrochemical Compression of Deuterium into a Metal Lattice"

This invention provides an electrode and method for preparing the electrode that may be employed to electrochemically compress deuterium into a metal lattice of the electrode. An electrochemical cell is constructed that includes an electrolyte solution comprising a metallic salt and a supporting electrolyte. The metallic salt, when in a reduced state, absorbs deuterium. Both the electrolytic solution and supporting electrolyte are dissolved in heavy water. An anode and cathode are immersed and stable within the electrolytic solution. The anode is stable when polarized. A voltage is applied across the anode and cathode while a constant potential is maintained at the cathode. The constant potential is measured with respect to a reference electrode immersed within the electrolytic solution so that deposition of metallic ions occurs in the presence of evolving deuterium during electrolysis of the electrolytic solution. By this method, the cathode is transformed into the electrode.

Navy case 73,311 (Serial 07/632,896) filed 24 December 1990; pending.

Stephen M. Hart

"Optoelectronically Controlled Frequency-Selective Surface"

A photovoltaic field-effect transistor (PVFET) is used to control the impedance, scattering frequency, and scattering cross-section of the scattering elements on a frequency-selective surface. The PVFETs are implanted in the arms of either wire or slot scatterers to make their scattering properties adjustable. The resulting optoelectronically controlled frequency-selective surface (OCFSS) becomes a programmable electromagnetic shield or pattern control device.

Navy case 76,915 (Serial 09/253,504) filed 19 February 1999; pending.

Richard Scheps

"Underwater Imaging Technique for the Detection of Shallow Submerged Objects"

This high-resolution underwater imaging and ranging device scans an area underwater with a pulsed laser and records the reflected signal from the illuminated area with a gated photomultiplier.

Navy case 77,222 (Serial 08/908,778) filed 7 August 1997; pending.

Stephen D. Russell
Randy L. Shimabukuro
Yu Wang

<div align="right">"Transmissive Surface-
Plasmon Light Valve</div>

The invention provides a light valve or optical modulating device that exploits color-selective absorption at a metal-dielectric interface by surface plasmons. The invention includes an electrode layer formed of an optically transparent substrate. A layer of electro-optic material is formed on the electrode. The electro-optic material has an index of refraction that may be modulated by an electrical bias. A second electrode is formed over the electro-optic material. Changes in a voltage bias across the electrodes modulate the index of refraction of the electro-optic material so that it selectively absorbs light (at different wavelengths) that passes through the light valve, depending on the index of refraction. The electrodes are made of a transparent or semitransparent material, such as indium tin oxide. Multiple light valves may be arranged in an array to form a flat-screen video display.

The novelty of the invention is that it provides a new mode of operation in that it is a transmissive device, rather than a reflective device.

Navy case 78,518 (Serial 09/172,581) filed 14 October 1998; pending.

Stephen D. Russell
Randy L. Shimabukuro
Yu Wang

<div align="right">"Microdynamic Optical Device"</div>

This invention describes a light valve, display, optical modulating device or optical filter that uses a microdynamic construction to exploit the color-selective absorption at a metal-dielectric interface by surface plasmons. This invention has applications for displays in command and control, for multispectral imaging in surveillance and reconnaissance, and for filtering in optical communications and scientific instrumentation.

Navy case 78,968 (Serial 09/607,579) filed 29 June 2000; pending.

Richard Scheps

<div align="right">"Compact Solid-State Dye Laser"</div>

This invention describes a compact solid-state dye laser that is diode-pumpable. The laser in its preferred embodiment consists of a monolithic state of materials including a solid-state l-μ-emitting laser gain element, a passive Q-switch, a second-harmonic doubling crystal, and the solid-state dye gain element.

Navy case 79,094 (Serial 09/539,460) filed 30 March 2000; pending.

Frank E. Hanson
Peter M. Poirier

"Technique for Operating High-Energy Q-switched 0.9-μm Neodymium Lasers"

This invention describes a wavelength discriminating filter and procedure to efficiently operate a Q-switched neodymium laser on the 4F3/2 to 4I9/2 transition near 0.9 μm by suppressing the higher gain emissions near 1 μm. The invention applies in general to all neodymium-based lasers operating at 0.9 μm and, in particular, to neodymium-doped yttrium aluminum garnet (Nd:YAG) operating at 0.0946 μm.

Navy case 79,523 (Serial 09/252,610) filed 4 February 1999; pending.

Pamela A. Boss
Stephen H. Lieberman

"Spectroelectrochemical Device to Detect Airborne Contaminants"

The invention is a gas sensor that combines the sensitivity of electrochemistry with the specificity of spectroscopy for detecting organic contaminants in the gas phase. The sensing unit consists of a micro-electrode assembly comprising an inner working disk electrode and an outer auxiliary ring electrode. The inner working disk electrode is coated with a thiol coating. The micro-electrode portion of the sensor is used to continuously monitor the environment. When current flow between the two electrodes of the sensor occurs, a spectrum of the working electrode can be obtained to identify the electro-active species. The invention can operate in either a flowing stream or a quiescent environment. It can also be used to monitor for dangerous volatile organics, explosives, or drugs. The invention may also be used to perform surface-enhanced Raman spectroscopy (SERS).

An important novelty of the invention is that it incorporates micro-electrodes and SERS, which combine to have the capability of detecting organic contaminants in the ppm level. The micro electrodes can be arranged in arrays and require reduced capacitive charging currents. Micro-electrodes exhibit reduced signal-to-noise characteristics over standard-sized electrodes and can be configured into a variety of shapes.

Navy case 79,709 (Serial 09/461,533) filed 15 December 1999: pending. (Navy case 78,928 was merged with this case.)

David F. Schwartz
J. William Helton
Jeffery C. Allen

"Predictor for Optimal Broadband Matching"

A predictor for optimal broadband matching of the present invention comprises a computer program that inputs samples of load reflectance normalized to characteristic line impedance, the frequencies associated with the normalized reflectance samples, and a parameter specifying the number of frequency increments for calculation. The program calculates and outputs the highest power gain obtainable by any matching circuit and two associated system parameters: the power mismatch and the voltage standing-wave ratio.

Navy case 79,796 (Serial 09/540,438) filed 31 March 2000; pending.

Pamela A. Boss
Roger D. Boss
Stephen H. Lieberman

**"Method of Preparing Durable
Gold or Silver Film Substrates
for Surface-Enhanced Raman
Spectroscopy (SERS)"**

This invention describes a process to prepare durable gold or silver films on substrates containing metal-oxide bonds for use in SERS. Steps in the process are (1) roughen the surface of the substrate, (2) react the roughened surface with a silanization agent such as (3-mercaptopropy) trimethoxy silane, (3) vacuum-deposit silver or gold onto the silanized surface, and (4) react with thiol coating. Depending upon the thiol coating used, these substrates can be used to detect VOCs, metal ions, and anions. Substrates prepared in this manner exhibit excellent adherence between the substrate surface and the metal film. The films can be immersed in water over extended periods of time. The silver or gold metal film can be used as the sensing layer of an optical waveguide device.

The substrates can be used by either the Navy or Marine Corps for environmental monitoring. The chemical modification of these substrates enables them to be used to detect and identify explosives, nerve agents, drugs, etc.

Navy case 79,987 (Serial 09/593,675) filed 14 June 2000; pending.

Steven J. Cowen

**"Method for Incorporating Total
Internal Reflection into a Flexible
Lithographic Mask"**

The novelty of the invention resides in the incorporation of critically angled surfaces to reflect unwanted optical energy out of the pattern mask. In the prior art, pattern masks that perform the frequency up-shifting function used energy-absorbing occluding layers to block unwanted light. However, such occluding layers had a tendency to accumulate heat energy that could damage the masks, and required low optical intensities to prevent mask damage. The invention allows the use of more intense optical irradiation of the pattern mask, thereby resulting in faster processing time.

Navy case 82,455 (Serial 09/605,036) filed 27 June 2000; pending.

INVENTION DISCLOSURES AUTHORIZED

Ayax D. Ramirez
Stephen D. Russell
Randy L. Shimabukuro

"Resonance-Tunable Optical Filter"

This invention exploits color-sensitive absorption at a metal dielectric interface by surface plasmons. The invention provides a resonance-tunable optical filter that includes a dielectric and a metal layer through which electromagnetic radiation may be transmitted or reflected. A beam-steering apparatus is used to change the incident angle of the electromagnetic radiation whose optical properties are modified by choice of incident angle. The incident medium and exit medium are optically transmissive. Unlike the prior art, the invention device does not require spacers, alignment layers, and seals previously used to make liquid crystal filled surface-plasmon devices.

Navy case 79,095; authorized for preparation of patent application, 11 April 2000.

Richard Scheps   **"Efficient Laser for High-Frequency Modulation"**

A dye laser pumped by a laser diode allows highly efficient modulation into the 100-Ghz range for high bandwidth communications.

Navy case 80,110; authorized for preparation of patent application, 30 July 2000.

Richard Scheps   **"Solid-State Lasers Pumped by Visible LEDs"**

An array of laser emitting devices (LEDs) emitting in the visible wavelength range is used to pump a solid-state laser rod that contains a transition element. The LEDs may operate continuous wave (CW) to generate a continuous laser emission, or they operate in pulsed mode to generate a pulsed laser emission. The LEDs may be coupled by an optical fiber to generate a pump beam along the fiber, or they may be focused. When pulsed, the LEDs generate much higher power for short periods of time, making possible high-output pulsed laser power. Exemplary lasers suitable for the present invention are Cr:LiSAF, which may be pumped in the red wavelengths, and $Ti:A1_2O_3$, which may be pumped in the green and blue wavelengths.

Navy case 82,321; authorized for preparation of patent application, 4 August 2000.

Stanislaw Szpak   **"Power Conversion Unit"**
Pamela A. Boss

This invention describes a power-conversion unit consisting of a working electrode and counter electrode. Palladium and deuterium are co-deposited on the working electrode. During co-deposition, nuclear events of unknown origin occur resulting in enormous heat release. This heat can be used to provide power for a number of applications.

Navy case 82,379; authorized for preparation of patent application, 28 June 2000.

INVENTION DISCLOSURES SUBMITTED

Stephen D. Russell   **"Interactive Display Device"**
Philip R. Kesten

This invention is a monolithically integrated display and sensor array that provides for interactive real-time changes to the display image.

Navy case 78,287; disclosure submitted 24 October 1996.

Stephen D. Russell   **"Solid-State Light Valve**
Randy L. Shimabukuro   **and Tunable Filter"**
Yu Wang

This invention describes an all solid-state light valve, optical modulating device or optical filter that uses color-selective absorption at a metal-dielectric interface by surface plasmons. The invention has applications for displays in command and control, for multispectral imaging in surveillance and reconnaissance, and for filtering in optical communications and scientific instrumentation.

Navy case 79,542; disclosure submitted 3 November 1997.

Stephen D. Russell   **"Spatially Conformable Tunable Filter"**

The invention provides a flexible or pliable optical modulating device, light-valve or optical filter. It uses a sheet of polymer-dispersed liquid crystal (PDLC) material and specifically selected thin-metal electrodes on either side of the PDLC to form a capacitor structure. When a voltage is applied to the capacitor, the refractive index of the liquid crystal changes since it is an electro-optic material. The optical properties of one of the thin-metal electrodes are selected in combination with the PDLC to have a surface-plasmon resonance that is either narrow band or broadband depending on the application. The surface plasmon is then used to selectively absorb incident light at the metal-PDLC interface, while the remaining light gets reflected (or transmitted). By varying the applied voltage, and its corresponding change in PDLC refractive index, we can modulate the light valve or tune the filter.

The improvement over the prior art is that this can be configured conformably over a surface to improve the acceptance angle for the filter and to simplify the fabrication of the device as compared to conventional liquid crystals.

Navy case 79,545; disclosure submitted 1 June 1998.

James D. Warner   **"Small-Boat Captive System"**
Thomas A. Knoebel
James R. Deuth

The small-boat capture device consists of two major components. The first component is a spring loop attached to the trailer and intersects the bow of the boat as it comes aboard the trailer. For the 10,000-lb small boat used in the initial application, a closing speed of 4.5 kn and a 1.5-inch-diameter nylon line provided the correct spring constant to provide a 2.5-g decelerate. The second component is a stainless-steel latching mechanism mounted to the bow of the small boat. The latch catches the line as it slides down the bow.

Navy case 79,950; disclosure submitted 22 January 1999.

Pamela A. Boss
Stephen H. Lieberman
Greg Theriault
Leonard J. Martini
Leon Smith

**"Thermo-Electrically Cooled
Sensor for Normal Raman (TE-NR)
Spectoscopy or Surface-Enhanced
Raman Spectroscopy (TE-SERS) to
Detect Subsurface Contaminants"**

The invention incorporates either a TE-NR or a TE-SERS sensor module inside a sampling, cone penetrometer probe. The inside of the probe is subdivided into three chambers—a lower sample chamber, a middle chamber housing either the TE-NR or TE-SERS sensor module, and an upper chamber housing the fiber optics. A water sample is taken into the lower chamber. It is then sparged with an inert gas to displace VOCs. VOC vapors are transported through a hydrophobic membrane and are concentrated onto a TE-cooled SERS substrate. The VOCs are identified and quantitated by either their Raman or SERS emissions.

Navy case 82,300; disclosure submitted 6 December 1999.

James Alsup

"Improved Comb-Spectrum Sensor"

A triplet-pair waveform for an active sonar is generated by an algorithm that provides good range resolution, high Doppler sensitivity, moderate bandwidth, and good power efficiency.

Navy case 82,302; disclosure submitted 14 December 1999.

Stuart H. Rubin

**"Hierarchical Phase
Translation Menus for
Object-Oriented Normalization
in Data Mining"**

A computer program assists in the capture of qualitative information, or phrases, in a classification system into a spreadsheet or database for data-mining application. The program presents the user with a series of pull-down menus to sort the data.

Navy case 82,394; disclosure submitted 21 March 2000.

Pamela A. Boss
Stephen H. Lieberman
Leonard J. Martini
Leon Smith

**"Fiber-Optic Sensor for Surface-
Enhanced Raman Spectroscopy
(SERS) to Detect Subsurface
Contaminants"**

The present invention comprises a fiber-optic probe fitted into a cone penetrometer module that draws a liquid sample from subsurface soil. The fiber-optic probe illuminates the sample and collects a Raman emission spectrum from the sample. The sample may then be purged from the module to allow another sample to be taken at a different soil depth.

Navy case 82,395; disclosure submitted 3 November 1999.

Richard Waters
Monti E. Aklufi

"Ultra-Sensitive, Micro-Electrical-Mechanical Systems (MEMS) Accelerometer"

The invention is a novel micro-electrical-mechanical system (MEMS) accelerometer that uses a light source for sensing acceleration.

Navy case 82,431; disclosure submitted 6 April 2000.

Pamela A. Boss
Stephen H. Lieberman

"Hand-Held, Fiber-Optic Sensor for Either Normal Raman (NR) Spectroscopy of Surface-Enhanced Raman Spectroscopy (SERS)"

The invention is a hand-held, fiber-optic sensor used to detect and identify VOCs, inorganic anions, metal ions, etc., by either normal Raman spectroscopy or SERS. The sensor head consists of an optical window and a fiber-optic bundle. For SERS, the window is coated with a thin silver or gold film that is optically transparent. The metal film is then reacted with a thiol to form a self-assembled monolayer (SAM). The chemical nature of the coating determines its selectivity.

Navy case 82,433; disclosure submitted 6 December 1999.

Pamela A. Boss
Stephen H. Lieberman

"Device to Detect Anionic Nutrients by Surface-Enhanced Raman Spectroscopy (SERS)"

This invention is a sensor that uses cationic-coated SERS substrates to detect anionic nutrients *in-situ* and in real time. For the Navy, information on nutrient dynamics is used to understand chemical reactions that impact marine environmental quality and to predict the distribution, growth, and community structure of biota in the coastal ocean.

Navy case 82,434; disclosure submitted 19 January 2000.

Douglass C. Evans
Joseph D. Aboumrad
Earl E. Floren

"Blazed-Grating Optical Fiber Polarizing Coupler"

This invention develops a technique to selectively remove one polarization state of light propagating in a single-mode optical fiber more than the other polarization state over a large range of wavelengths. The light-carrying fiber is induced to radiate an accurately controllable percentage of its light by the introduction of a blazed Bragg grating into its core region for a few millimeters of length. The blaze, or tilt, of the periodic perturbation is selected to maximize polarization discrimination. The scattered light is incident on the outer surface of an identical fiber that is located in close proximity and in parallel to the first fiber. The identical grating in the second fiber scatters light radiated from the first fiber into its guided direction of propagation with maximum polarization discrimination.

SSC San Diego case 398; disclosure submitted 14 April 2000.

Ray H. Pettit

**"A Maximum Likelihood Based
Frequency Synchronizer for
Dual-h, Full-Response 4-ary
Continuous-Phase Modulation (CPM)"**

Maximum likelihood (ML) techniques are useful in finding synchronizer structures for various cases. Synchronizers for frequency, phase, and timing have been found for various bandpass signaling techniques such as phase shift keying (PSK), differential phase shift keying (DPSK), quadrature amplitude modulation (QAM), minimum shift keying (MSK), and continuous phase modulation (CPM). These include data-aided, decision-directed, and clock-aided cases. For CPM, however, apparently only the single modulation index case has ML-based synchronizers. This invention provides a new nondata-aided, nondecision-directed MO-based frequency synchronizer (with no phase or timing information), derived for a full-response, dual-h (two modulation indexes), 4-ary CPM signaling scheme.

SSC San Diego case 404; disclosure submitted 27 June 2000.

**INVENTION DISCLOSURES IN PREPARATION
(SSC SAN DIEGO AND NAVY CASE NUMBERS PENDING)**

Jon Losee
J. Charles Hicks
Everett W. Jacobs
Wayne C. McGinnis
Roger D. Boss

**"Boron Nitride Solid-State Detector for
Thermal Neutrons"**

David W. J. Stein

**"Whitened Vector Quantization
for Energy and Anomaly Detection"**

David W. J. Stein

**"A Method for Enhancing
Anomaly Detection for Signals
Known up to a Subspace"**

David W. J. Stein

**"A Method for Detecting Known
and Anomalous Materials in
Compositional Data Using
Stochastic Classes"**

David W. J. Stein

**"A Method for Analyzing
Compositional Data Using
Stochastic Classes"**

PROJECT TABLES

SSC San Diego FY 00 ILIR Database

Project Title	Principal Investigator	PI Code	Phone (619) 55	DoD MA1	DoD MA2	FY99 $(K)	FY00 $(K)	FY01 $(K) (Planned)	FY02 $(K) (Planned)	FY03 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	Most Strongly Supported FNC	Next Most Strongly Supported FNC	ONR Sub-Element Supported
Sonar Waveform Design	J. Alsup	D712	32498	OSV	ASW	0	89	0	0	0	acoustic detection and detectors; undersea and antisubmarine warfare;	US-6	MW-3	6	9	14
Telesonar Transmission Channel Models	P. Baxley	D857	33107	CCC	OSV	96.6	119	0	0	0	underwater acoustic propagation; transmission channels; propagation models; telesonar; sound scattering	US-6	ID-2	1	5	31/11
Fiber Optic Gyroscope Dead Band Analysis	J.J. Del Colliano	D314	31516	CCC	MOB	0	80	0	0	0	navigation and guidance	ED-1	IR-3	1	9	21
Change Blindness: Understanding Our Visual Representation of Objects and Scenes	J.C. DiVita	D44209	36461	CCC		0	45	0	0	0	change blindness, scene perception, visual memory, object perception	HP-3	HP-4	3	2	15
Distributed Quality Collaboration	J.J. Drummond	D4123	34131	CCC		0	27	0	0	0	computer systems	HP-1	IT-1	5	3	15
Antijam techniques for GPS utilizing nonlinear processing	Dr. H. Dyckman	D33	33829	CCC	MOB	0	89	0	0	0	GPS, antijam, nonlinear	ED-1	PL-8	9	12	14
Deduction in Data Fusion Based Upon Algebraic Representation of Probabilistic Models	Dr. I.R. Goodman	D4223	34014	CCC		96.6	98	0	0	0	data fusion; expectation of random sets; generalized estimation; relational event algebras	HP-1	HP-2	3	5	14
Development of Improvements to the UHF Advanced Digital Waveform	S.J. Graser	D844	39691	CCC	ELW	0	98	0	0	0	radio communications	IT-4	IT-3	5	3	14
Adaptive Intelligent Agents in Informative Environments	B.J. Hafner	D4123	35538	CCC		0	54	0	0	0	computer systems	ID-1	HP-1	1	3	15
Coherent Mid-IR Optical Parametric Oscillator	Dr. F. Hanson	D853	32094	OSV	ELW	92.4	89	0	0	0	lasers; nonlinear optics; laser radar	IR-2	PL-1	7	9	11
Wireless Network Resource Allocation with QoS Guarantees	S. Lapic	D882	33073	CCC		92.4	94	0	0	0	communications; wireless networks	IT-4	IT-3	3	1	21

NOTES: MA = Mission Area; FNC = Future Naval Capability (codes)

See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

Project Title	Principal Investigator	PI Code	Phone (619) 55	DoD MA1	DoD MA2	FY99 $(K)	FY00 $(K)	FY01 $(K) (Planned)	FY02 $(K) (Planned)	FY03 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	Most Strongly Supported FNC	Next Most Strongly Supported FNC	ONR Sub-Element Supported
Reasoning With Uncertainty about Complex Information and Events	Dr. R. Larsen	D441	34142	CCC		0	28	0	0	0	multi-process algebra data; conditional event algebra and probability logic; maximum entropy	HP-1	HP-3	3	5	14
Software Agents for Dissemination of Sensor Information and Tasking	J. McDonnell	D745	35762	CCC		0	72	0	0	0	miscellaneous detection and detectors	HP-1	HP-2	3	5	15
Electronic Properties of Cubic Boron Nitride	Dr. W. McGinnis	D364	35610	MWT		46.2	72	0	0	0	semiconductors; electronics	RF-3	RF-1			21
Applications of Stochastic Nonlinear Dynamics to Communication Arrays	Dr. B. Meadows	D364	32823	CCC		90	134	0	0	0	command and communications; nonlinear dynamics; stochastic	IT-4	IT-3	5	12	14
Innovative Methods for Alertness Management	Dr. S. Murray	D374	36350	CCC	PMD	91.3	62.5	0	0	0	alertness; human factors; human computer inter-action; psychophysiology	HP-3	HP-4	2	3	15
Laser Optical Parametric Oscillator for mid-IR	J. Myers	D743	32599	CCC		84	45	0			laser; optical; oscillator	NR-17	33-3	7	9	11
Sensitivity of Marine Mammals to Low-Frequency Acoustic Pressure and Particle Motion	Dr. S. Ridgway	D3503	31374	MIW		50.4	54	0	0	0	marine mammals; acoustics; particle motion	MT-4	OE-9	8	11	31
Super Composite Slotted Cylinder Projector	Dr. P. Tang	D746	31938	OSV	ASW	84	80	0	0	0	laminated composite materials; actuator; active materials; wall-driven projector; slotted cylinder projector	UW-6	MW-3	6	11	11
Enhanced Coordinate Registration for ROTHR	Dr. W. Torrez	D7212	32020	CCC	MWT	0	55.5	0	0	0	active and passive radar detection	ID-5	ID-2	5	7	14

NOTES: MA = Mission Area; FNC = Future Naval Capability (codes)

See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

SSC San Diego FY 01 ILIR Database

Project Title	Principal Investigator	PI Code	Phone (619) 55	DoD MA1	DoD MA2	FY99 $(K)	FY00 $(K)	FY01 $(K) (Planned)	FY02 $(K) (Planned)	FY03 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	Most Strongly Supported FNC	Next Most Strongly Supported FNC	ONR Sub-Element Supported
CRANOF: A Complexity-Reducing Algorithm for Near-Optimal Fusion with Direct Applications to Integration of Attribute and Kinematic Information	Dr. D. Bamber	D44215	39219	CCC	INT	0	0	160	160	160	sensor fusion, complexity reduction, rule-based systems, uncertainty, probability logic, linguistic information, second-order probability, nonmonotonic reasoning	ID-5	HP-2	3	1	14/41
Acoustic Modeling in the Littoral Regime	P. Baxley	D857	33107	CCC	OSV	0	0	60	60	60	telesonar, underwater acoustic communications, channel model, beam tracing	US-6	ID-2	1	5	31/1
Detection of Ionic Nutrients in Aqueous Environments Using Surface Enhanced Raman Spectroscopy (SERS)	Dr. P.Boss	D363	31603	MWT	MWT	79.8	89	60	0	0	sensors; surface enhanced Raman spectroscopy	OE-9	OE-11	11	12	13
Automatic Matched Field Tracking	Dr. H. Bucker	D857	33093	CCC	OSV	0	71	125	125	0	acoustics; acoustic detection and detectors	US-6	US-5	1	5	11
Information Fusion with Entropy and Conditionals (IFWEC)	Dr. P. Calabrese	D73H	33680	INT	OSV	0	0	150	150	150	entropy, uncertainty, conditionals, events, propositions, logic, probability, complexity	ID-5	HP-2	3	5	14/15
Modeling of Acoustic Radiation in the Time-Domain with Applications to Non-Linear Structure-Acoustic Interaction Problems	Dr. S. Hobbs	D711	22018	ASW	OSV	0	0	100	100	100	acoustics, radiation, time-domain Kirchoff integral equation	US-6	US-7	6	9	14
Chaos Control and Nonlinear Dynamics in Antenna Arrays	Dr. V. In	D364	39287	CCC		0	0	300	300	300	chaos, nonlinear dynamics, stochastic	IT-4	IT-3	5	12	14

NOTES: MA = Mission Area; FNC = Future Naval Capability (codes)
      See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

SSC San Diego FY 01 ILIR Database (contd)

Project Title	Principal Investigator	PI Code	Phone (619) 55	DoD MA1	DoD MA2	FY99 $(K)	FY00 $(K)	FY01 $(K) (Planned)	FY02 $(K) (Planned)	FY03 $(K) (Planned)	Keywords	Most Strongly Supported ONR/NRL Thrust	Next Most Strongly Supported ONR/NRL Thrust	Most Strongly Supported FNC	Next Most Strongly Supported FNC	ONR Sub-Element Supported
Neaconing: Network Meaconing for Improved Security	A. Judd	D44207	34255	CCC		0	0	115	115	115	network, fingerprint, hacker, security, adaptable, intrusion, scan	IT-6	IT-1	3	5	15
Integration of Complex Information	D. Lange	D4221	36534	CCC	INT	53.8	45	120	0	0	hypermedia; knowledge base; plan	HP-1	HP-3	3	5	15
High Linearity Broadband Fiber Optic Link using Electroabsorption Modulators with a Novel Dual Wavelength Second Harmonic Cancellation Scheme.	R. Nguyen	D894	35435	CCC	ELW	0	98	140	0	0	fiber optics, photonic link, electro-absorption (EA) modulator.	IT-4	RF-2	5	7	11
Adaptive Distributed Object Architecture (ADOA)	W. Ray	D44207	34150	CCC		0	0	140	140	140	computer systems	ID-2	HP-2	3	2	15
Towards an Assessment of Flow-Induced Bioluminescent Signatures	Dr. J. Rohr	D363	31604	OSV	SPW	0	0	115	115	115	bioluminescence, flow visualization	IR-2	OE-4	6	2	31/24
Knowledge Mining for Command and Control Systems	Dr. S Rubin	D73A	33554	CCC	FSO	0	295	300	300	0	knowledge mining; mining tools	ID-3	ID-5	3	1	15
Advanced Hyperspectral Data Processing	Dr. D. Stein	D743	32533	MWT		75.6	125	120	0	0	hyperspectral data; data processing; stochastic; linear un-mixing; detection	ID-4	PL-7	6	1	14
Nucleic Acid Transfection Technology Development in Marine Mammals	Dr. B.Van Bonn	D352	31869	FSO	MIW	0	0	110	110	110	marine mammals, preventive medicine, nucleic acid, vaccines, plasmic	MT-4	CP-2	8	12	41/42
Micro-Electro-Mechanical Systems Ultra-Sensitive Accelerometer (MEMS USA)	Dr. R.L. Waters	D856	36404	MOB	STW	0	0	150	150	150	MEMS, accelerometer, navigation, inertial, optical resonant cavity, Fabry-Perot, micro electronics	ED-2	ED-1	7	12	11
Robust Waveform Design for Tactical Communication Channels	Dr. J.R. Zeidler	D8505	31581	CCC		0	385	300	300	0	radio communications	IT-4	IT-3	5	12	14

NOTES: MA = Mission Area; FNC = Future Naval Capability (codes)

See Appendix for DoD Mission Area abbreviations, ONR Sub-Element Codes, and ONR/NRL Corporate Thrusts sorted by research area.

GLOSSARY

GLOSSARY

3-D	Three-Dimensional
3DGBQD	3-D Gaussian Beam/Quadrature Detector
ADW	Advanced Digital Waveform
AJ	Antijam
ASEE	American Society for Engineering Education
ASW	Antisubmarine Warfare
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BRF	Birefringent Filter
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAD	Collaborative Agent Design
CBR	Case-Based Reasoning
CCK	Complementary Code Keying
CCOF	Command Center of the Future
CCSK	Cyclic Code Shift Keying
CDMA	Code Division Multiple Access
CFAR	Constant False Alarm Rate
CIC	Combat Information Center
CMOS	Complementary Metal-Oxide Semiconductor
CNR	Carrier-to-Noise Ratio
CONOPS	Concept of Operations
COTS	Commercial-off-the-Shelf
CPM	Continuous Phase Modulation
CRADA	Cooperative Research and Development Agreement
CRD	Constrained, Regularized Deconvolution
CW	Continuous Wave
CYC	Cyclopedic Knowledge Base
DIA	Defense Intelligence Agency
DON	Department of the Navy
DPSK	Differential Phase Shift Keying
DSAT	Dynamic Sensor Allocation and Tasking
DSP	Digital Signal Processor
DSS	Decision Support System
EA	Electro-Absorption
EBL	Explanation-Based Learning
ELB	Extending the Littoral Battlespace
EMI	Electro-Magnetic Interference

EO	Electro-Optic
ES	Expert Systems
FFT	Fast Fourier Transform
FM	Frequency Modulation
FNC	Future Naval Capability
FRONT	Front-Resolving Observational Network with Telemetry
GaN	Gallium Nitride
GAP	Generalized Assignment Problem
GBT	Geometric Beam Tracing
GPS	Global Positioning Satellite
GRB	Gaussian Ray Bundle
HFS	Hermite Function Space
HMMWV	High-Mobility Multipurpose Wheeled Vehicle
HSI	Hyperspectral Imagery
IC-Ag	Icationic-Coated Silver
ICCE	International Conference on Composite Engineering
ID	Identification
IGARSS	International Geoscience and Remote Sensing Symposium
IMMACCS	Integrated Marine Multi-Agent command and Control System
ILIR	In-house Laboratory Independent Research
I/O	Input/Output
IP	Internet Protocol
IR	Infrared
ISAR	Information, Surveillance, and Reconnaissance
ISI	Intelligent Systems Division
	Intersymbol Interference
JASA	Journal of the Accoustical Society of America
JTIDS	Joint Tactical Information Distribution System
KTA	Potassium Titanyl Arsenate
LAN	Local Area Network
LOC	Large Optical Cavity
LPD	Low Probability of Detection
LUM	Linear Unmixing
MCTMS	(3-Mercaptopropyl]-Trimethoxysilane
MFSK	M-ary Frequency Shift Keying
MILSTATCOM	Military Satellite Communications
ML	Maximum Likelihood
MLS	Maximal Length Sequences

MMLS	Modified Maximal Length Sequences
MNF	Maximum Noise Fraction
Mo	Molybdenum
MOS	M-ary Orthogonal Signaling
M-QAM	M-ary Quadrature Amplitude Modulation
MSK	Minimum Shift Keying
MVRTW	Multi-Vehicle Routing with Time Windows
NCC	Naval Communications Channels
NEMO	Naval EarthMap Observer
NP	New Professionals
	Nondeterministic Polynomial
NSWC	Naval Surface Weapons Center
OCDM	Orthogonal Code Division Multiplexing
OFDM	Orthogonal Frequency Division Multiplexing
OMFTS	Operational Maneuvers from the Sea
OPO	Optical Parametric Oscillator
ORB	Object Request Broker
PC	Principal Component
PFA	Probability of False Alarm
PLL	Phase-Locked Loop
PN	Pseudorandom
PPLN	Periodically Poled Lithium Niobate
PPM	Pulse Position Modulation
PSK	Phase Shift Keying
PZT	Piezoelectric Translator
QAM	Quadrature Amplitude Modulation
QD	Quadrature Detector
QoS	Quality Of Service
QPSK	Quadrature Phase Shift Keying
RDS	Remote Deployable Systems
REDS	Real-Time Decision Support
RF	Radio Frequency
RMI	Remote Methods Invocation
RS	Random Sequence
RTAS	Real-Time Technology and Applications Symposium
RX	Reed–Xioali
SAM	Self-Assembled Monolayer
SampTA	Sampling Theory and Applications
SATCOM	Satellite Communication
SDSU	San Diego State University

SEM	Stochastic Expectation Maximization
SERS	Surface-Enhanced Raman Spectroscopy
SFM	Super Frequency Modulation
SGB	Simple Gaussian Beams
SGS	Silver Gallium Sulfide
SiC	Silicon Carbide
SMM	Stochastic Mixture Modeling
SNR	Signal-to-Noise Ratio
SPE	Solid-Phase Extraction
SPIE	Society of Photo-Optical Instrumentation Engineers (also know as the International Society for Optical Engineering)
SRMT	Surveillance and Reconnaissance Management Tool
SSP	Signal-Subspace Preservation
STO	Sensor Tasking Order
UCSD	University of California at San Diego
USC	University of Southern California
UHF	Ultra High Frequency
UV-VIS	Ultraviolet Visible
VLA	Vertical Line Array
VQ	Vector Quantization
WDM	Wavelength Division Multiplexing
WVQ	Whitened Vector Quantization

APPENDIX: DATABASE DEFINITIONS

APPENDIX: DATABASE DEFINITIONS

ONR Sub-Element Codes

Codes	Topic	Codes	Topic
11	General Physics	24	Energy Conversion
12	Radiation Sciences	31	Ocean Sciences
13	Chemistry	32	Ocean Geophysics
14	Mathematics	33	Atmospheric Sciences
15	Computer Science	34	Astronomy and Astrophysics
21	Electronics	35	Environmental Science
22	Materials	41	Cognitive and Neural Sciences
23	Mechanics	42	Medical Science
		52	Multidisciplinary Support

DoD Mission Areas

Codes	Letter Code	Topic	Codes	Letter Code	Topic
1	AAW	Anti-Air Warfare	10	MIW	Mine Warfare/Mine Countermeas.
2	AMC	Amphibious Warfare	11	MOB	Mobility
3	ASU	Anti-Surface Ship Warfare	12	MWT	Multi-Warfare Technology
4	ASW	Anti-Submarine Warfare	13	OSV	Ocean Surveillance
5	CCC	Command, Control & Comm.	14	PMD	Personnel/Medical
6	ELW	Electronic Warfare	15	SBS	Sea-Based Strategic Warfare
7	FSO	Fleet Support Operations	16	SPW	Special Warfare
8	INT	Intelligence	17	STW	Strike Warfare
9	LOG	Logistics	18	TNG	Training

ONR/NRL S&T Corporate Thrusts Sorted by Research Area

Research Areas	Corporate Thrusts	Designations
Strike		**ST**
	Autonomous Real-Time Targeting	-1
	Land Attack and ASUW	-2
RF Technologies and Architectures		**RF**
	RF Sensors for Surface/Aerospace Surveillance	-1
	Advanced Multi-Function RF System (AMRFS)	-2
	Solid State Electronics	-3
	Vacuum Electronics	-4
Information Dominance		**ID**
	Defensive Information Warfare	-1
	Common Operational/Tactical Picture & Visualization	-2
	Networked Combat System and Operations	-3
	Image Processing, Analysis, & Exploitation	-4
	Multi-Sensor Fusion for Surface/Aerospace Surveillance	-5
	Extending the Littoral Battle Space	-6
Platform and Theater Defense		**PL**
	Electronic Combat Mission Support	-1
	Electronic Combat Threat Warning	-2
	Electronic Combat Self Protection	-3
	Radar Arrays	-4
	Network-Centric EW	-5
	Simulation/Visualization/Planning	-6
	Threat Detection/Classification/ID	-7
	Onboard Jammers	-8
	Offboard/Expendables	-9
	Survivability/Lethality	-10
	Air Dominance	-11
	Theater Air Missile Defense	-12
Undersea Warfare		**US**
	Shallow Water Signal Processing	-1
	Environmental Adaptive Sonar Technology	-2
	Shallow Water Active ASW	-3
	Undersea Warfare Effectiveness	-4
	Cooperative ASW	-5
	Wide Area ASW Surveillance	-6
	Battlegroup ASW Defense	-7
	Undersea Weaponry	-8
Mine Warfares		**MW**
	Mine Countermeasures	-1
	Organic Minehunting (Sensing/Processing)	-2
	Mine/Obstacle Neutralization	-3
	Mine Sweeping/Jamming	-4

Advance Force Operations	-5
Mining	-6
Sustainment	**SU**
Maintenance Reduction Technology	-1
Condition Based Maintenance	-2
Strategic Systems Sustainment	-3
Logistics	-4
Expeditionary Operations	**EO**
Expeditionary Operations	-1
Operational Environments	**OE**
Space/Airborne Sensor Development	-1
Remote/Space Sensing Processes	-2
Space/Airborne Sensor Exploitation and Demonstration	-3
Environmental Processes	-4
Ocean, atmosphere & Space Model Development	-5
Environmental Sensors & Data	-6
Data Assimilation and Information Exploitation	-7
Validation Studies	-8
Environmental Quality and Environmental Biology	-9
Pattern Recognition	-10
Environmental Effects	-11
Surface and Subsurface Platforms	**SS**
High Power Solid State Macro Electronics	-1
Littoral Support Craft	-2
Electrically Reconfigurable Ship	-3
Advanced Hull Forms	-4
Hydromechanics	-5
Hull Life Assurance	-6
Automation to Reduce Manning	-7
Advanced Electrical Power Systems	-8
Reduced Signatures	-9
Air Platforms	**AP**
Air Vehicles	-1
Propulsion and Power	-2
Integrated Avionics, Displays and Advanced Cockpit	-3
Survivability and Signature Control	-4
Autonomous Ops (Uninhabited Combat Air Vehicle)	-5
Space Platforms	**SP**
Spacecraft Technology	-1
Ground Platforms	**GP**
Ground Combat Vehicles Systems Technology	-1
Human Performance	**HP**
Decision Support & Collaboration for Optimal Mission Planning and Execution	-1
Decision Aids	-2
Human Factors & Reduced Manning	-3

Manpower, Personnel & Training	-4
Medical Technology & Biocentric Technology	**MT**
Casualty Prevention	-1
Fit & Healthy Force	-2
Combat Casualty Care & Management	-3
Marine Mammals	-4
Biorobotics	-5
Biosensors, Biomaterials, Bioprocesses	-6
Chemical-Biological Defense	-7
Materials and Structures	**MS**
Naval Materials	-1
Functional Materials	-2
Synthesis, Processes & Characterization	-3
Prediction & Simulation	-4
Energetic Materials and Lethality	**EM**
Energy Conversion	-1
Electronics (Materials & Devices)	**ED**
Navigation and Timekeeping	-1
Sensing, Diagnostics & Detectors	-2
Nanoscience	-3
Plasma Science and Technology	-4
Visible and IR	**IR**
EO/IR Electronics	-1
EO/IR Sensors for Surface/Aerospace Surveillance	-2
Electro-Optics	-3
Information Technology & Operations	**IT**
Dependable, Real-time High-Assurance Information Systems	-1
Intelligent Software and Autonomous Systems	-2
Maritime/Military Radio Communications	-3
Dynamic Wireless Networks	-4
Submarine Communications	-5
Security	-6
Computational Methods	-7
Industrial Programs	**IP**
Modeling and Simulation for Design, Engineering and Acquisition	-1
Metals Processing and Fabrication	-2
Advanced Manufacturing Enterprise	-3
Composite Processing and Fabrication	-4
General Manufacturing Issues	-5
Energetics Processing and Fabrication	-6
Electronics Processing and Fabrication	-7
Affordability Programs	-8
Dual Use Program	-9
Technology Transfer Program/IR&D	-10

Warfare Analysis and Experimentation	WA
Assessments and Studies	-1
Modeling and Simulation	-2
Kainotyping, Fleet/Corps Battle Experiments	-3
Corporate Programs	CP
Naval Science Assistance Program	-1
In-House Laboratory Independent Research (ILIR)	-2
Textual Data Mining	-3
S&E Education and Career Development	-4
SBIR/STTR Program	-5

AUTHOR INDEX

Code	Contributor	Page	Code	Contributor	Page
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D857	Baxley, Paul A.	45	D859	Nguyen, Richard	65
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